SUNLIGHT AND GLARE

The impact of Sun Patches on the Light Balance of Indoor Spaces

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Por

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Front Cover:

Hélène Binet. LF one (Landscape Formation one). Event and exhibition space for the Garden Festival in Weil am Rhein, Zaha Hadid, 1999.

Source: Binet, H. (2000). *Architecture of Zaha Hadid in photographs by Helen Binet*. Baden: Lars Müller Publishers. ISBN: 3907078128

JACK: Julie, what are you doing here?

JULIE: Just watching the light changing.

Jim Jarmush

Down by law, 1986.

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Abstract

The overall objective of the thesis is to encourage the presence of sunlight in indoor spaces. The specific aim is to show that a good daylighting design can incorporate the solar reflection on the surfaces and increase the overall light level, without provoking the excessive contrast that causes glare.

A literature review demonstrates the value of sunlight. The testimony of professional photographers specialised in architecture describes the interest of a visual experience. The scientific works stress the predilection that users feel in relation to the presence of sunlight and provide information on its positive effects on health. People spend more and more time indoors and, therefore, their satisfaction requires the introduction of sunlight. A journey through history discovers the works and rules that are quintessential examples of good lighting design. Nevertheless, the current legislation is lacking in that it only considers quantitative aspects (distribution of minimum light levels). The qualitative aspects (visual interest linked to the vision of light) should be part of the design more often; the challenge is to customise tools with which to assess the balance of visible light in spaces.

The purpose of the glare indices is to warn if the light contrast is excessive. This is particularly difficult as these indices intend to assess the reaction of the visual perception, which is partially subjective. The attempts to validate the indices are numerous. This thesis analyses eight glare indices and chooses two to be included in an assessment methodology based on the reading of HDR images. The development of a script allows a data-processing succession, using some tools featured in programs such as Radiance, Webhdrtools and Evalglare. The methodology includes the assessment of the impact of different calibration parameters belonging to the camera (centre of bracketing) and those of the calculation instructions (calibration factor and threshold definition of the glare source) to ensure the reliability of the calculations under conditions of sunlight.

The measurements were made in summer, at various scenarios located in two cities. In London, the first case considered a singular office lit thanks to roof and side windows (two façades). The outcome was compared with the perception of observers with different nationalities and lighting cultures. Then, two meeting rooms permitted the assessment of the perception of a significant number of visual fields. The different orientation of the rooms (north and south) allowed the comparison of the effects of the solar presence inside or outside. In both cases, two variables were included: the window size and the contribution of the artificial light. In Barcelona, two other meeting rooms were analysed, having both deeper solar penetrations due to the west orientation. This feature led to the consideration of the effects of several sunlight control devices: roller shutters, roller screens and vertical slats. Finally, in Barcelona, a final case served to judge a space under new conditions, characterised by a small window ratio in relation to the total façade and a southwest orientation that, according to the time of day, toggled the solar presence inside and outside.

The results lead to specific conclusions depending on the type of solar penetration, due to the orientation, and the position that users occupy. Their joint contribution suggests that the glare indices rarely describe a disturbing or intolerable situation that would complicate a visual task. Therefore, except for the situations where the radiation falls on working surfaces, the design can incorporate the solar presence in the interiors in order to improve the lighting and thermal conditions.

Resumen

El objetivo general de la tesis es fomentar la presencia de la luz solar en los espacios interiores. La finalidad es demostrar que un buen diseño de iluminación natural puede incorporar la reflexión solar en las superficies y aumentar el nivel lumínico general sin que el contraste sea excesivo y cause deslumbramiento.

Una revisión bibliográfica pone en valor la presencia de la luz solar en los interiores. El testimonio de fotógrafos profesionales especializados en arquitectura describe el interés de una experiencia visual. Los trabajos científicos destacan la predilección que sienten los usuarios por la presencia de la luz solar e informan de sus efectos saludables. Los individuos pasan cada vez más horas en espacios interiores y, por tanto, su satisfacción requiere la introducción de luz solar. Un recorrido por la historia descubre las obras y las normas que son muestras ejemplares de un buen diseño lumínico. Sin embargo, la legislación actual muestra carencias cuando únicamente afronta aspectos cuantitativos (reparto de niveles lumínicos mínimos). Los aspectos cualitativos (interés vinculado a la visión de la luz) deberían formar parte del diseño más a menudo; el reto implica dotarse de herramientas de evaluación del equilibrio de la luz visible en los espacios.

El propósito de los índices de deslumbramiento es advertir si un contraste lumínico es excesivo. La dificultad es notable ya que estos índices pretenden prever la reacción de la percepción visual, parcialmente subjetiva. Las tentativas para validar los índices son numerosas. La tesis analiza ocho índices de deslumbramiento y escoge dos para introducirlos en una metodología de evaluación basada en la lectura de imágenes HDR. El desarrollo de un ‘script’ permite encadenar procedimientos informáticos que aprovechan herramientas de Radiance, Webhdrtools y Evalglare. La metodología incluye la valoración de la repercusión de diferentes parámetros de calibración propios de la cámara (centro del horquillado) y de las instrucciones de cálculo (factor de calibración y umbral de definición de la fuente deslumbramiento) para garantizar la fiabilidad de los cálculos en condiciones de luz solar.

Las mediciones sucedieron en verano, en escenarios diversos ubicados en dos ciudades. En Londres, el primer caso consideró una oficina singular, con luz cenital y lateral (dos fachadas). La obtención de resultados fue comparada con la percepción de unos observadores de nacionalidades y culturas lumínicas distintas. A continuación, dos salas de reunión permitieron evaluar la percepción de un notable número de campos visuales. La distinta orientación de las salas (norte y sur) permitió comparar los efectos de la presencia solar en el interior o en el exterior. En ambos casos, dos variables fueron incorporadas: el tamaño de ventana y la contribución de la luz artificial. En Barcelona, dos otras salas de reunión fueron analizadas, ambas con penetraciones solares más profundas a causa de la orientación oeste. Esta particularidad dio lugar a la consideración de los efectos de diferentes dispositivos de control de la luz solar: persianas o cortinas enrollables y lamas verticales. Finalmente, en Barcelona, un último caso sirvió para juzgar un espacio con condiciones distintas a las anteriores, caracterizado por una proporción de ventana pequeña en relación a la totalidad de la fachada y por una orientación suroeste que, según la hora del día, alternaba la presencia solar en el interior y en el exterior.

Los resultados dan lugar a conclusiones específicas en función del tipo de penetración solar según las orientaciones y de la posición que ocupan los usuarios. Su contribución conjunta permite afirmar que los índices de deslumbramiento describen situaciones molestas o perturbadoras para una tarea visual en muy pocas ocasiones. Por tanto, exceptuando las situaciones en que la radiación incide sobre las superficies de trabajo, el diseño puede incorporar la presencia solar en los interiores con el fin de contribuir lumínicamente o térmicamente.

In memory of those who enlighten the sky, to my father, to Rafi.

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Firstly, I have fond memories of my father’s advice encouraging me in my endeavour to make headway, with a profound respect for work and people. There is no doubt that progress and scientific rigour rests upon this grounded advice.

Nor can I overlook the tremendous privilege of relying on the participation of Prof. Rafael Serra, who supervised the initial stages of this thesis. Misfortune did not allow us to complete it together. Fortune led Dr. Helena Coch to take over from him as the director of this thesis.

One day, a friend told me her secret of how to combat the emptiness left by the most painful of losses. Without fearing that memories should slip into oblivion, she advised me to do all that I could to fill this emptiness with new personal experiences.

Being awarded a grant for a research stay abroad opened up the doors for new links in London. There it was possible for me to work with two researchers, who have been vital in the development of this thesis.

My most sincere thanks to Prof. Mike Wilson for offering me his so valuable, kind and constant advice. His experience and intuition have been essential in underlining and fostering the most interesting aspects of this thesis.

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Furthermore, in order to put these evaluation methods into practice, the opportunity to access all the tools and manuals freely made available to the scientific community by the Radiance collective has been of incalculable help.

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Note to the reader

This thesis has been written in two EU community languages: English and Spanish. The entire text has been written in English, with the exception of Chapters 2 and 3, written in Spanish. These two chapters are preceded by an English translation of the introductory summary of its content. Chapter 1, defining the thesis, includes all its content written in Spanish.

Nota al lector

Esta tesis ha sido escrita en dos lenguas comunitarias de la UE: inglés y español. La totalidad del texto aparece escrita en inglés, exceptuando los capítulos 2 y 3 escritos en español. Estos dos capítulos están precedidos por una traducción al inglés del resumen introductorio de su contenido. El capítulo 1 de definición de la tesis incluye la totalidad de su contenido escrito en español.

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Contents

Chapter 1: Thesis definition

1.1 Context of study

Since the beginning of history of architecture, designers describe the presence of daylight with admiration, seduced by the manifestation of its intangible nature. Frequently, their accumulated knowledge and creative capacity are the only tools they have for solving, with admirable skill, the difficult challenge of modelling the light by means of the architectural form. Architects use their own works to investigate and make judgments as suggestive as the following: “The very clever combination of the two light sources (direct and diffuse) is the secret formula of the prodigy” (Campo Baeza, 1996).

In 1966, Ralph Hopkinson published *Daylighting*. Until today, this book is an obligatory reference for the daylighting design of buildings. Thanks to this publication, designing with daylight is no longer an intuitive task and becomes a science. The presence of daylight can be measured and, therefore, rationalized. Hopkinson adapts the fundamentals of lighting technology to the field of daylight. Its interest considers the amount of incidental light on the surfaces and, simultaneously, the quality of this light when reflected and visualised by users. Furthermore, Hopkinson details the formulation of a glare index adapted to the particularities of daylight. In his opinion, the application of this index is essential to assess the balance of vision within the spaces and identify the possible risk of an excessive contrast.

Since then, the definition and validation of the glare indexes that are specific for daylighting is a challenge for the experts in lighting. Their efforts seek to prove the existence of good correlation between the judgment of contrast dictated by the glare indexes and the subjective appraisal of users, which is expressed in their responses through questionnaires. Usually, their results are not satisfactory.

In itself, the definition of glare is complex and, firstly, requires the distinction between three types of glare: disability glare, discomfort glare and veiling or glare reflections (Van den Berg *et al.*, 1991; CIE, 2002; IDAE, 2005). Disability glare defines an excessive glare that can impair and damage the vision. Discomfort glare causes an annoying or distracting effect but is not necessarily harmful to vision. Therefore, discomfort glare means to perceive a lower magnitude of contrast, if compared to that of disability glare. Veiling or glare reflections reduce contrast on screens and they may be a significant problem in office spaces.

The assessment of glare under daylight conditions is complex due to the dynamism of the glare sources. The sky brightness is constantly changing depending on the time of the day and the passing of seasons. The solar presence is triply variable. The intensity, size and position of the sun patches never stay constant. The complexity of the assessment is also due to the informative interest contained in the glaring surfaces. The case of the window is clear as it contains the desired view of the exterior. Given these difficulties, the glare indexes are continually revised. Even the results of certain researches cast doubt on the criteria that others had previously validated (Osterhaus, 2005).

In addition to what is written in *Daylighting*, Hopkinson published numerous papers related to the glare topic (Hopkinson, 1926, 1929, 1960, 1963, 1970/71, 1972). Beyond the requirements demanded by the architectural uses and the types of visual tasks, the question that interests him is the type of light source that causes glare. His titles do not mention the sun reflections and focus on the windows and artificial light ceilings, considering that both are large sources of light. Therefore, the issue is not whether the light source is artificial or natural. The key aspect is the size of the source (small or large). The most recent researches incorporate Hopkinson's work. Once surpassed the style of continuous luminous ceilings, most of the works focus on the high luminous contrast between interior and exterior that cause the windows.

Despite the repeated efforts, the specialists in daylighting find it difficult to agree on the utilization of a glare index that offers guarantees of good correlation with the users' perception. Consequently, regulations do not incorporate the scientific approaches to judge the balance of the visible light, a key requirement to ensure visual comfort.

Designers tend to not apply the innovative approaches if there is not a regulatory framework that validates them. The pragmatic and intuitive knowledge remains the primary tool used to model the presence of daylight in indoor spaces.

The development of computer science and, more recently, high technology linked to the world of the image, provide researchers with a greater potential to test the reliability of the glare indexes. Firstly, these new tools enable a more thorough calculation; computer procedures allow reading the information contained in each pixel on an image, its conversion into values in photometry units and, ultimately, the computing of the algorithms that calculate the glare indexes (Ward, 1998a; Jacobs, 2007, 2012). Secondly, beyond the analysis of real situations captured via digital photography, computer resources allow the simulation of spaces lit by artificial or natural sources. Through the incorporation of the data recorded at meteorological stations, the research works consider a higher degree of complexity. The simulations compute long calculation procedures that consider the daily and seasonal variability typical of daylight (Reinhart, 2001). Then, the project decisions with repercussions in lighting can be evaluated with greater consistency. The possibilities offered by computers do not end there: some computerized procedures propose dynamic evaluations that, besides the lighting effects, incorporate the thermal effects that impact on the project decisions. The purpose of these approaches is to assess the overall energy performance of a building (Reinhart & Wienold, 2011).

The recent research identifies the technological fields in which the application of the glare indexes is relevant. The shading devices are a frequent case of study (Reinhart, 2001). Regarding the use of the spaces, the offices are often the natural field of the studies. The visual tasks linked to the office work are demanding and require high lighting performance. In addition, offices are the place where most of the workers carry out their daily activities (Wienold, 2010). Proof of this is that in 1997, for the first time, the offices housed more than 50% of work activity (Redlich, 1997). The same year, in Sweden, the Swedish energy consumption of offices over the last 25 years appeared published (Nilson, 1997). While heating and hot water reduced their consumption of fossil fuels by half, electricity doubled it.

Simultaneously, other research studies evaluate the performance of the first integrated control systems of natural and artificial light. The goal of these systems is to improve energy efficiency and lighting comfort (Littlefair, 1999). Curiously, users often disable them. The photo sensors, which regulate these systems, try to maintain uniform and constant the lighting level. Apparently, this approach is wrong. Other methods, which are related to the users' visual comfort, seem to be required (Cunill, 2008). Glare regains its importance as a possible indicator for the adjustments of these systems.

In parallel to this course, the research works of Nuanwan Tuaycharoen and Peter Tregenza (2005, 2007) propose a further degree of difficulty when they consider the glare sources. Its working hypothesis seeks to show that users are more tolerant of lighting contrast when their vision contemplates environments that are interesting or pleasurable to them. The view through the windows is a clear example. Users spend long hours in artificial working environments and feel attraction for the view of images that suggest them the sensory pleasure that offers the natural environment. Such desire justifies their responses to surveys that show a lower degree of annoyance in front of the luminous contrast between the inside and outside when users contemplate natural environments through the windows.

In the same line of work some investigations include, besides the window, the sun presence in the discussion (Boubekri, 1991, 1992). The vision of the sun patches indoors also includes certain information content that interests to users and justifies their greater acceptance of contrasts. The vision of the sun patches indoors also includes certain informative content that interests users and justifies their greater acceptance of contrasts. In a way, the solar presence connects with the natural phenomenon that occurs outdoors. Users become aware of the biological rhythms that contribute to their welfare. The course of the day and seasons introduces variations in the intensity and colour of sunlight. Intuitively, users acknowledge these changes and feel comfort when they witness the visual rhythmic of the passing time. Moreover, the solar presence entails the appearance of noticeable contrasts of light indoors. A lighting environment characterized by the presence of light and shadow emphasizes the modelling of spaces and gives them greater intelligibility and vigour (Tanazaki, 1998). These qualities are not present in the spaces illuminated with diffuse and constant lights. Undoubtedly, these two types of daylighting establish a clear aesthetic distinction between the spaces located in climates with overcast or clear skies (Tregenza & Wilson, 2011).

The inclination of Mohamed Boubekri (2008) for sunlit environments is clear. His research happens in the United States, a territory that promulgated the benefits of solar architecture in the 70s as an antidote to combat the energetic insufficiency, which was indicated by the first oil crisis. The sunny West Coast took the lead and led initiatives that solved thermal conditioning with passive solutions that ensured energy savings. In addition to the American context, the Algerian origin of Boubekri could also explain his preference for the presence of sunlight in indoor spaces. His research examines the position occupied by the sun patches in the space with the aim of defining an appropriate separation distance between the user and the visual task that he performs. Moreover, Boubekri considers the sunlight presence in a broader sense. His papers determine in which extent sunlight benefits the health of users (Boubekri, 2004a) and the mistake that implies that the standards do not keep in mind the presence of sunlight in interiors (Boubekri 2004b).

A literature review leads up to discover that the greater solar shortage, which is characteristic of the British territory, justifies that it was there where the initial efforts to regulate the solar presence in interiors were appreciated. The first attempt is now historic because it was contemporary to the First World War (BSI, 1945). Thirty years later, Hopkinson returns as the protagonist and, together with Newton Watson, leads the project *Sunlight in Buildings* (Hopkinson & Watson, 1973/74), at the request of the Department of Environment, which aims to revise the 1945 project and implement new considerations in the British Code of Practice (B.S.I., 1982). Its initial objective is to identify users' preferences regarding sunlight presence in relation to the architectural uses (Ne’eman, Craddock, & Hopkinson, 1976). In relation to this, the second part of their work recommends the minimum and maximum hours of solar presence for different types of interiors (Ne’eman, Light, & Hopkinson, 1976). A substantial part of the research project is published in papers in which Eliyahu Ne'eman, being the person responsible for the project, appears as first author. In the presence of sunlight, the correlation between the users' reactions and the measurements (calculations of contrast and glare) is also part of the project interests (Ne'eman, 1977). This time, the experimental methods do not permit to demonstrate the correlation. Habitually, Ne'eman was regular contributor to the Technion, belonging to the Israel Institute of Technology, in Haifa, Israel. Again, a scientist of Mediterranean origin emphasizes the interest of sunlight presence in interiors.

This thesis also finds a development framework at the crossroads between the Mediterranean and British culture. Its beginning and conception depart from the home territory of its author: the Mediterranean. Its development is the result of the scientific exchange with researchers from British universities. A research project funded by the AGAUR agency allows the development, in London, of a methodology for judging the presence of sunlight indoors. The HDR photographic techniques and the use of two glare indexes (DGI and DGP) are the cornerstones of this methodology. The main objective of the thesis is to test the reliability of these two indices to judge the contrasts that sunlight causes in interiors. The purpose is to explore the potential of sunlight to illuminate interiors without provoking risk of glare.

1.2 Thesis objectives

Two main objectives motivate the writing of this thesis. The first is to encourage the presence of sunlight in indoor spaces. Specifically, the aim is to demonstrate that a good daylighting design can incorporate the sun presence without causing excessive contrast. Or, stated the other way around, the goal would be to prevent the consolidation of a prejudice that link the presence of solar radiation at a high risk of glare. This objective does not mean to ignore the situations where such risk does exist. The purposes of this thesis include identifying these situations, analysing its causes and suggesting the appropriate solutions.

The tolerance to the sun presence in interiors implies a consequence that, for being so obvious, runs the risk to go undetected. Often, the solar access is closely associated with the exterior view through the window. Therefore, the restriction of solar access continuously, for an excessive fear of the risk of glare or a lack of dynamism and flexibility of the shading devices, would imply to lose the desired exterior view and a great potential of natural lighting. Many studies isolate the study of the window as light source and as possible cause of excessive contrasts between the interior and exterior. Part of the originality of this thesis is to address jointly the effect of the window and solar access; both bright surfaces are light sources and potential causes of glare.

The second aim of the thesis is to provide new arguments to validate the glare calculations as a tool for judging a good lighting design of indoor spaces. Current standards rarely go beyond the strictly quantitative assessment of the distribution of the incidental light (measured in lux), which is invisible to the users. They perceive the light when it is reflected on surfaces (measured in cd/m2) and judge the visual quality and the experienced comfort depending on the contrast between the different brightness levels. The formulation of the glare indexes, which is based on a logarithmic expression, is faithful to the peculiarities of human vision. However, the adjustments of the formulation and the definition of the thresholds that judge the excessive contrast require, even today, further work to ensure the reliability of their calculations. The sunlit scenarios are appropriate to test the formulation in front of situations that are characterized by the existence of possibly extreme contrasts.

This thesis faces a third objective, which is methodological, in order to answer the two main objectives described above. The objective consists in programming a script (lines of computer commands) that enables a suitable response to two technical issues. The first tests, under sunlight conditions, the measurement ranges that perform the HDR photographs. The second allows the joint and comparative work with two glare indexes (DGI and DGP). The methodology aims to give arguments to discuss the sensitivity of these two indexes under different lighting scenarios, which are motivated by various combinations: user position, orientation of the space, existence of control devices and combination of daylight and artificial light.

1.3 Hypothesis of the thesis

The definition of the working hypothesis steps forward in favour of concreteness. Repeatedly, the common link of the hypothesis is the consideration of the most relevant factors in assessing the light balance between the brightest surfaces ('sun patches'[1] and windows) and the remaining darker surfaces, considered as the visual background. The risk of glare is always under judgement. Of the three types of glare, the one known as discomfort glare is the spotlight of the hypotheses. Therefore, the two other types (disability glare and veiling reflections) are relegated to comments of a lower impact. Firstly, the following statements underline five general hypotheses, sorted by their degree of relevance.

Hypothesis 1: The sun patches indoors are generally less glaring than preconceived since they involve a significant increase of the background luminance.

The explanation that, *a priori*, would validate this hypothesis is as follows: frequently, the joint action of the type of solar access (imposed by the orientation of the space) and the position that the users occupy minimizes the risk of glare. Although the sun patches are surfaces with a high brightness, its position usually appears on the outer perimeter of the room, near the window and away from the centre of attention of the user's visual task. From this position, the sun patches would reflect the light and act as a second large light source, which has a notable intensity, slightly equivalent to that of the window. Its effect would increase the luminance of the background and, therefore, reduce the contrast and the risk of glare. This situation is common in the south façades of buildings in European latitudes, which explain the verticality of the solar radiation and the frequent lack of solar access in the deepest parts of the spaces. The urban contexts favour even more this type of solar access in the interiors; the horizontal solar radiation has fewer options of penetrating due to the obstructions that provoke the high urban densities.

[1] Henceforth, the term 'sun patch' will refer to the sun presence that is reflected on the interior and exterior surfaces.

Even more, given the conditions described above, the same hypothesis could be expressed more radically and state that the presence of sun patches indoors improves the light balance between the interior and exterior. We could find the explanation in the great difference between the luminances of the exterior and interior, being the exterior ones much higher. The sun patches, understood as a second extended light, would demonstrate their effectiveness to rebalance the light in the vision of the scene.

Hypothesis 2: The sun patches that are present inside cause a lesser degree of glare than those that remain outside, viewed through the window.

The explanation that supports this hypothesis is as follows: in these cases, the glaring surfaces could not achieve to increase the average luminance of these interiors that would remain obscure. The contrast between the bright vision outside and the darkness inside would be even more exaggerated and would lead to a significant risk of glare. The north-facing spaces are the most characteristic of this type of situation. However, it is less common that the glare studies pay attention to these cases.

Hypothesis 3: When the sun patches occupy deep positions within the spaces, its effect is not the cause of the most severe degrees of glare. The predictable view of the sun and its halo is the main cause of this type of annoyance.

Different aspects could validate the formulation of this hypothesis: first, the strong inclination of the sun's rays would not cause extreme luminance values. Instead, its contribution would raise the average luminance of the scene. Consequently, the sun patches would become part of the background luminance and would stop being considered as glaring surfaces. The situation would only be critical when there is specular reflexion on the finish of the interior surfaces. In these cases, only a small part of the sun patches, which corresponds to the reflection of the sun's circumference, would be the cause of discomfort. This case would occur only at specific moments, in which users confront the reflection. However, in such a situation, rather than the vision of the reflection, the really annoying issue would be the appearance of the sun and its halo within the visual field. With which, in these cases, the cause of glare would not be as much the presence of the sun patches indoors as the vision of the high luminance of the sky through the window. In other words, the annoyance would not be caused by the light imbalances (discomfort glare), but rather by the disability that provokes the vision of an excessive light within the visual field (disability glare).

Hypothesis 4: The risk of glare is remarkably greater when users occupy frontal positions in relation to the windows.

Glare is a parameter linked to the vision of the users. Therefore, it depends not only on the position of the sun patch inside (or outside) of the space. The user position is also fundamental. Two types of positions are common inside the spaces: frontal or lateral in relation to the window. Clearly, the frontal positions are the most critical in terms of glare. Two reasons justify this hypothesis. First, glare is lesser when the vision of the bright surfaces occupies the periphery of the visual field. In this regard, the formulation of glare includes a position coefficient, which is sensitive to this visual feature. Second, from these frontal positions, at some depth within the space, the vision of the darkest surfaces (roof, floor and side walls) predominates. If this hypothesis is confirmed, the solution to decrease the risk of glare is simple: avoid furniture arrangements involving frontal visions of the windows.

The very expression of the formulation of the glare indexes anticipates this hypothesis as it contains a position coefficient whose mission is to minimize the impact of the shiny surfaces that occupy peripheral positions within the visual field. However, it is convenient to proceed with the evaluation of the case studies in order to verify experimentally the weighting of the results by means of this coefficient.

Hypothesis 5: The DGI glare index is more reliable than the DGP if the objective is to describe the balance of daylight.

This last general hypothesis addresses the reliability of the glare indexes depending on the type of light scene. The DGP index would seem rather to be related to glare caused by an excessive amount of light (a high value of Ev). However, the DGI index would seem to be more linked to the vision of the light contrast between the inside and the outside or, said more generically, between the brightest surfaces (including the sun patches) and the background that contains them. This last general hypothesis is also suggested by the mathematical expression of the formulations corresponding to these two glare indexes. Again, the case studies will be useful to verify to what extent this hypothesis is true.

The next four hypotheses consider the efficiency of the lighting control devices that participate in the control of glare. Later, the case studies will test its validity through the introduction of certain variables that will permit comparative deductions.

Hypothesis 6: The potential of artificial lighting is insufficient to correct the imbalances caused by daylight.

Often, in the presence of an excessive luminous contrast between the interior and exterior, users turn on the light to counteract the apparent lack of light indoors. However, this contribution is insufficient. The artificial lighting devices tend to direct the light to the tables, over which a certain level of light is required for the development of the visual tasks. Its contribution to increase of the illumination of the walls is low. Usually, the walls are very apparent within the visual fields of the horizontal glances that judge the general lighting of the interiors. If its luminance is low, the average luminance of the background also runs the risk of being too low to offset the imbalance caused by the high luminance of the glare sources.

Hypothesis 7: If the windows are small, the risk of glare is greater than when they are large or very large.

In the presence of large windows, the view of the sky and the presence of sun patches increase the average luminance of the scene. This effect compensates the contrast between the interior and exterior. This does not happen if the windows are small. The contribution of the sky and the sun patches is insufficient to compensate the light of the scene. The interior remains dark in relation to the high brightness of the sky and the sun patches.

Hypothesis 8: Under sunlight conditions, the risk of glare varies little throughout a day or within the same season when the space is oriented facing south or north. The situation is less constant in spaces oriented facing east or west.

The reading of a stereographic sun-path diagram justifies the formulation of this hypothesis. The comparison of some days with others within the same season allows identifying that the sun paths are quite similar. Therefore, the positions of the sun patches into the space register little change within the same season. The situation also remains quite stable in the north and south facades along the different hours of one single day. The situation is different for the east and west façades. The rapid changes in the position of the sun during the sunrise and sunset provoke constant variations in the position of the sun patches that cause alterations in the risk of glare. Similarly, the solar incidence over these last façades is very different if we compare the sun path in summer and winter. The design of the shading devices is especially critical for these façades.

Hypothesis 9: In the east and west facades, roller screens ensure better control of glare than roller shutters and vertical slats.

The previous hypothesis refers to the rapid changes that register the solar altitude and azimuth during the hours when the radiation has impact on the east and west façades. These changes require a continuous operation of the position of the shutters and the slats, if the goal is to control glare without provoking an excessive darkness in the interior. However, screens allow transparency. Since the solar incidence starts, the screens can cover the entire window. A good design of its degree of transparency allows a certain view of the outside, minimises the solar access, provokes the diffuse transmission of light and, finally, reduces notably the degree of glare.

1.4 Structure of the thesis

Six chapters structure the development of this thesis (figure 1.1). **Chapter 1** introduces and defines the thesis; it justifies the theme and presents the objectives to be achieved and the starting hypotheses.

Chapters 2 and 3 introduce the background and the bases of this research. In **Chapter 2**, a literature review enhances the presence of sunlight in interiors. The testimony of professional photographers specialised in architecture describes the interest of the visual experiences. The scientist works emphasise the users' preference for the presence of sunlight and provide information on its positive effects on health. A journey through history discovers the works and standards that are quintessential examples of good lighting design. Nevertheless, the current legislation is lacking in that it only considers quantitative aspects (distribution of minimum light levels). The qualitative aspects (visual interest linked to the vision of light) should be part of the design more often; the challenge is to customise tools with which to assess of the balance of the visible light in the spaces.

Chapter 3 focuses on the glare indexes whose purpose is to warn if the light contrast is excessive. This is particularly difficult as these indexes intend to assess the reaction of the visual perception, which is partially subjective. The attempts to validate the indexes are numerous. This chapter analyses eight glare indexes and chooses two to be included in an assessment methodology based on the reading of HDR images.

Chapter 4 presents the details of the working methods. The development of a script allows a data-processing succession, using some tools featured in programs such as Radiance, Webhdrtools and Evalglare, to analyse the risk of glare in the portrayed scenes through HDR images. The methodology includes the assessment of the impact of different calibration parameters belonging to the camera (centre of bracketing) and those of the calculation instructions (calibration factor and threshold definition of the glare source) to ensure the reliability of the calculations under conditions of sunlight.

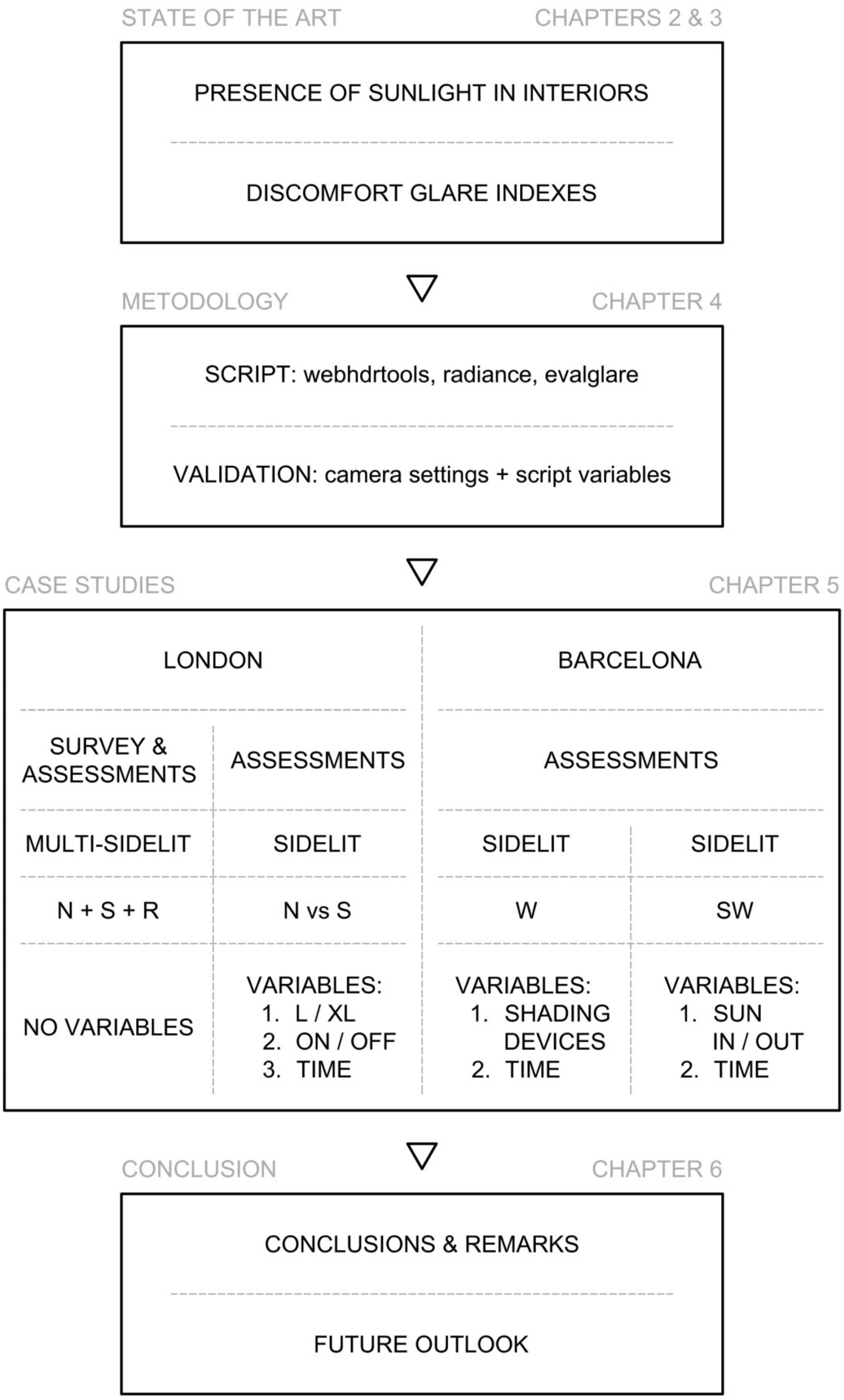

Fig. 1.1. Structure of the thesis

Chapter 5 presents the conditions, results, comments and partial conclusions of each experiment. The measurements were made in summer, at various scenarios located in two cities. In London, the first case considered a singular office lit thanks to roof and side windows (two façades). The outcome was compared with the perception of observers with different nationalities and lighting cultures. Then, two meeting rooms permitted the assessment of the perception of a significant number of visual fields. The different orientation of the rooms (north and south) allowed the comparison of the effects of the solar presence inside or outside. In both cases, two variables were included: the window size and the contribution of the artificial light. In Barcelona, two other meeting rooms were analysed, having both deeper solar penetrations due to their west orientation. This feature led to the consideration of the effects of several sunlight control devices: roller shutters, roller screens and vertical slats. Finally, in Barcelona, a final case served to judge a space under new conditions, characterised by a small window ratio in relation to the total façade and a southwest orientation that, according to the time of day, toggled the solar presence inside and outside.

Finally, in **Chapter 6**, the results lead to specific conclusions depending on the type of solar penetration, due to the orientation, and the position that users occupy. These specific conclusions respond to the starting hypothesis. Moreover, their joint contribution suggests in which situations the solar presence generates excessively unbalanced indoor lighting conditions that could cause glare to the users. Ultimately, Chapter 6 suggests new experimental procedures that would give stronger support the conclusions of this thesis and other alternatives that would make possible further approaches.

Following the chapters, two appendices are attached. **Appendix A** presents the questionnaire that was used for the development of the first case studies that correlate the responses of users and the results of the glare calculations. **Appendix B** includes two publications carried out during the period of this thesis. The first one (PLEA 2011) considers the thermal effects of the sunlight (in summer and winter) in order to recommend design options; its contribution complements the work of this thesis, whose content is only focused on the lighting effects of sunlight. The second article (WREF 2012) considers the assessment of glare in scenes under conditions of daylight; its objective is to determine the impact that would have on the results the use of two different functions in order to weight the effect of the luminances according to their position within the observer's visual field. This issue is clearly linked to the content of this thesis.

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Capítulo 1: Definición de la tesis

1.1 Contexto de estudio

Desde los inicios de la historia de la arquitectura, los proyectistas describen la presencia de la luz natural con admiración, seducidos por la manifestación de lo intangible. Frecuentemente, el saber acumulado y la capacidad creativa son las únicas herramientas con las que ellos cuentan para resolver, con admirable destreza, el difícil reto que supone modelar la luz a través de la forma arquitectónica. Los arquitectos utilizan sus propias obras para investigar y formular sentencias tan sugerentes como la siguiente: “La muy sabia combinación entre las dos fuentes de luz (directa y difusa) es la fórmula secreta del prodigio” (Campo Baeza, 1996).

En 1966, Ralph Hopkinson publica *Daylighting*. Aun hoy, su libro es una referencia obligada para diseñar la iluminación natural de los edificios. Gracias a esta publicación, proyectar con la luz natural deja de ser una tarea intuitiva y se convierte en una ciencia. La presencia de la luz natural puede ser medida y, por lo tanto, racionalizada. Hopkinson traduce los fundamentos de la luminotecnia al campo de la luz natural. Su interés abarca la cantidad de luz que incide sobre las superficies y, al mismo tiempo, la calidad de esa luz cuando es reflejada y visualizada por los usuarios. Además, Hopkinson detalla los pormenores de un índice de deslumbramiento adaptado a las particularidades de luz natural. Según su opinión, la aplicación de este índice es fundamental para valorar el equilibrio de la visión dentro de los espacios e identificar el posible riesgo de un contraste excesivo.

Desde entonces, la concreción y validación de los índices de deslumbramiento específicos para la iluminación natural es un reto para los expertos en iluminación. Sus esfuerzos tratan de demostrar la existencia de una buena correlación entre el juicio del contraste dictaminado por los índices y la apreciación subjetiva de los usuarios, expresada en sus respuestas a través de cuestionarios. Los resultados no suelen ser satisfactorios.

La propia definición del deslumbramiento es compleja y, en primer lugar, requiere diferenciar entre tres tipos de deslumbramiento: perturbador, molesto y por velo o reflexión (Van den Berg *et al.*, 1991; CIE, 2002; IDAE, 2005). El deslumbramiento perturbador (“disability glare”) describe un deslumbramiento excesivo que puede perjudicar y dañar la visión. El deslumbramiento molesto (“discomfort glare”) causa un efecto molesto o de distracción pero que no es necesariamente perjudicial para la visión. Por tanto, un deslumbramiento molesto supone percibir una menor magnitud de contraste si la comparamos con la de un deslumbramiento perturbador. El deslumbramiento por velo o reflexión (“veiling or glare reflections”) reduce el contraste en los monitores y puede ser un problema significativo en los espacios de oficina.

La evaluación del deslumbramiento en condiciones de iluminación natural es compleja debido el dinamismo de las fuentes deslumbrantes. El brillo del cielo cambia constantemente en función de la hora del día y del paso de las estaciones. La presencia solar es triplemente variable. La intensidad, el tamaño y la posición de los parches de sol nunca permanecen constantes. La complejidad de la evaluación también viene determinada por el interés informativo contenido en las superficies deslumbrantes. El caso de la ventana es patente ya que contiene la deseada visión del exterior. Ante tales dificultades, los índices de deslumbramiento propuestos son continuamente revisados. Incluso los resultados de ciertos trabajos ponen en duda los criterios que otros habían validado anteriormente (Osterhaus, 2005).

Además de lo escrito en *Daylighting*, Hopkinson publica numerosos artículos relacionados con la temática del deslumbramiento (Hopkinson, 1926, 1929, 1960, 1963, 1970/71, 1972). Más allá de los requisitos que exigen los usos arquitectónicos y los tipos de tareas visuales, la cuestión que centra la atención de Hopkinson es el tipo de fuente luminosa que causa el deslumbramiento. Sus títulos no mencionan los reflejos solares y se centran en las ventanas y los techos luminosos artificiales, considerando que ambos son fuentes luminosas extensas. Por lo tanto, la cuestión no reside en que la fuente luminosa sea artificial o natural. El aspecto fundamental es el tamaño de la fuente (puntual o extensa). Las investigaciones más recientes incorporan el trabajo de Hopkinson. Una vez superada la moda pasajera de los techos luminosos continuos, la mayor parte de los trabajos ponen el acento en el alto contraste lumínico que causan las ventanas entre el interior y el exterior.

Pese a los esfuerzos reiterados, los especialistas en iluminación natural encuentran dificultades para consensuar la utilización de un índice de deslumbramiento que ofrezca garantías de buena correlación con la percepción de los usuarios. En consecuencia, las normativas no incorporan las aproximaciones científicas para juzgar el equilibrio de la luz visible, un requisito fundamental para garantizar el confort visual. Los proyectistas tienden a no aplicar los métodos innovadores si no existe un marco normativo que los valide. El conocimiento pragmático e intuitivo sigue siendo la principal herramienta que utilizan para modelar la presencia de la luz natural en los interiores.

El desarrollo de la informática y, más recientemente, de la alta tecnología vinculada al mundo de la imagen, dotan a los investigadores de un mayor potencial para poner a prueba la fiabilidad de los índices de deslumbramiento. En primer lugar, estas nuevas herramientas permiten un cálculo más exhaustivo; los procedimientos informáticos permiten la lectura de la información contenida en cada píxel de una imagen, su conversión en valores con unidades lumínicas y, en última instancia, la computación de los algoritmos que calculan los índices de deslumbramiento (Ward, 1998a; Jacobs, 2007, 2012). En segundo lugar, más allá del análisis de situaciones reales capturadas a través de fotografías digitales, los recursos informáticos permiten la simulación de espacios iluminados por fuentes artificiales o naturales. A través de la incorporación de los datos registrados en estaciones meteorológicas, los trabajos plantean un grado mayor de complejidad. Las simulaciones encadenan unos largos procedimientos de cálculo que consideran la variabilidad diaria y estacional propia de la luz natural (Reinhart, 2001). Las decisiones de proyecto con repercusiones lumínicas pueden entonces evaluarse con una mayor consistencia. Las posibilidades que ofrece la informática no acaban ahí: algunos procedimientos informáticos plantean evaluaciones dinámicas que, además de los efectos lumínicos, incorporan los efectos térmicos que tienen repercusiones sobre las decisiones de proyecto. La finalidad de estos planteamientos es evaluar el comportamiento energético global de un edificio (Reinhart & Wienold, 2011).

La investigación reciente identifica los campos tecnológicos en los que la aplicación de los índices de deslumbramiento es relevante. Los dispositivos de control de la radiación solar son un caso de estudio frecuente (Reinhart, 2001). En relación al uso de los espacios, las oficinas suelen ser el terreno natural de los estudios. Las tareas visuales propias del trabajo de oficina son exigentes y requieren altas prestaciones lumínicas. Además, las oficinas son el lugar donde la mayor parte de los trabajadores desarrollan su actividad cotidiana (Wienold, 2010). Prueba de ello es que en 1997, por primera vez, las oficinas alojaban más del 50% de la actividad laboral (Redlich, 1997). El mismo año, en Suecia, los consumos energéticos de las oficinas suecas asociados a los últimos 25 años aparecían publicados (Nilson, 1997). Mientras que la calefacción y el agua caliente habían reducido su consumo de energía fósil a la mitad, la electricidad lo duplicaba.

Simultáneamente, otras investigaciones evalúan el funcionamiento de los primeros sistemas de control integrado de la luz natural y artificial. El objetivo de estos sistemas es compatibilizar la eficiencia energética y el confort lumínico (Littlefair, 1999). Curiosamente, los usuarios suelen desactivarlos. Los fotosensores que regulan dichos sistemas pretenden mantener constante el nivel lumínico. Aparentemente, este criterio es erróneo. Otros métodos, asociados al confort de la visión del usuario, parecen ser requeridos (Cunill, 2008). El deslumbramiento recobra su importancia como posible indicador para la regulación de estos sistemas.

En paralelo a este transcurso, los trabajos de Nuanwan Tuaycharoen y Peter Tregenza (2005, 2007) introducen un grado más de dificultad cuando consideran las fuentes de deslumbramiento. Su hipótesis de trabajo pretende demostrar que los usuarios son más tolerantes ante el contraste lumínico cuando su visión contempla entornos que les son interesantes o placenteros. La visión a través de las ventanas es un claro ejemplo. Los usuarios pasan largas jornadas en entornos de trabajo artificiales y sienten inclinación por la visión de imágenes que les sugieran el placer sensorial que ofrece el ambiente natural. Tal deseo justifica sus respuestas a encuestas que demuestran un menor grado de molestia ante el contraste lumínico entre el interior y el exterior cuando los usuarios contemplan entornos naturales a través de las ventanas.

En la misma línea de trabajo están las investigaciones que, además de la ventana, introducen la presencia solar en la discusión (Boubekri, 1991, 1992). La visión de los parches solares en un interior también incorpora un cierto contenido informativo que interesa a los usuarios y justifica su mayor aceptación de contrastes. En cierto modo, la presencia solar pone en contacto con el fenómeno natural que ocurre en el exterior. Los usuarios toman conciencia de los ritmos biológicos que contribuyen en su bienestar. El transcurso del día y de las estaciones introduce variaciones en la intensidad y en el color de la luz solar. Intuitivamente, los usuarios reconocen estos cambios y sienten confort al presenciar la rítmica visual propia del paso del tiempo. Además, la presencia solar conlleva la aparición de marcados contrastes lumínicos en los interiores. Un ambiente lumínico caracterizado por la presencia de luces y sombras acentúa el modelado de los espacios y les dota de mayor inteligibilidad y vigor (Tanazaki, 1998). Estas cualidades no están presentes en los espacios iluminados con luces difusas y constantes. Sin duda, estos dos tipos de iluminación natural establecen una clara distinción estética entre los espacios interiores propios de los climas con cielos cubiertos o despejados (Tregenza & Wilson, 2011).

La inclinación de Mohamed Boubekri (2008) por los ambientes iluminados con luz solar es clara. Sus investigaciones suceden en los EEUU, un territorio que promulgó los beneficios de la arquitectura solar durante los años 70 como antídoto para combatir la insuficiencia energética señalada por la primera crisis del petróleo. La soleada costa oeste del país tomó la delantera y lideró las iniciativas que solventaban en acondicionamiento térmico con soluciones pasivas que garantizaban el ahorro energético. Además del contexto americano, la procedencia argelina de Boubekri también podría explicar su predilección por la presencia de la luz solar en los interiores. Su investigación estudia la posición que ocupan los parches solares en el espacio con la intención de definir una distancia apropiada de separación entre el usuario y la tarea visual que realiza. Además, Boubekri considera la presencia solar en un sentido más amplio. Sus artículos determinan en qué medida la luz solar beneficia la salud de los usuarios (Boubekri, 2004a) y el error que supone que las normas no contemplen la presencia solar en los interiores (Boubekri 2004b).

Una revisión bibliográfica lleva a descubrir que la mayor escasez solar propia del territorio británico justifica que sea allí donde se aprecian esfuerzos iniciales por regular la presencia solar en los interiores. La primera tentativa es ya histórica puesto que es contemporánea a la Primera Guerra Mundial (B.S.I., 1945). Treinta años más tarde, Hopkinson vuelve a ser el protagonista y, junto con Newton Watson, lidera el proyecto *Sunlight in Buildings* (Hopkinson & Watson, 1973/74), un encargo del

Department of Environment, que pretende revisar el proyecto de 1945 e implementar las nuevas consideraciones en el British Code of Practice (B.S.I., 1982). Su objetivo inicial es determinar las preferencias de los usuarios respecto a la presencia solar en función de los usos arquitectónicos (Ne'eman, Craddock, & Hopkinson, 1976). En relación a ello, una segunda parte del trabajo define las horas mínimas y máximas de presencia solar recomendables para los distintos tipos de interiores (Ne'eman, Light, & Hopkinson, 1976). Una parte substancial del proyecto de investigación aparece publicada en artículos en los que Eliyahu Ne'eman, siendo la persona responsable del proyecto, aparece como primer autor. En presencia de luz solar, la correlación entre las reacciones de los usuarios y las mediciones (cálculos de contraste y de deslumbramiento) también forma parte de los intereses del proyecto (Ne'eman, 1977). En esta ocasión, los métodos experimentales no permiten demostrar la correlación. Habitualmente, Ne'eman era colaborador habitual del Technion, perteneciente al Israel Institute of Technology, en Haifa, Israel. De nuevo, un científico de origen mediterráneo pone el acento en el interés de la presencia de la luz solar en los interiores.

La presente tesis también encuentra un marco de desarrollo en el cruce entre la cultura británica y la mediterránea. Sus inicios y concepción parten del territorio natal de su autor: el Mediterráneo. Su desarrollo es fruto del intercambio científico con investigadores de universidades británicas. Un proyecto de investigación financiado por la agencia AGAUR permite la elaboración en Londres de una metodología para juzgar la presencia de la luz solar en los interiores. Las técnicas fotográficas HDR y el uso de dos índices de deslumbramiento (DGI y DGP) son los pilares de esta metodología. El principal objetivo de la tesis es poner a prueba la fiabilidad de estos dos índices para juzgar los contrastes que ocasiona la luz solar en los interiores. La finalidad es explorar las posibilidades que ofrece la luz solar para iluminar los interiores sin que su presencia implique un riesgo de deslumbramiento.

1.2 Objetivos de la tesis

Dos objetivos principales motivan la redacción de esta tesis. El primero es fomentar la presencia de la luz solar en los espacios interiores. Concretamente, la finalidad es demostrar que un buen diseño de iluminación natural puede incorporar la presencia solar sin causar un excesivo contraste. O, expresado al revés, el objetivo sería evitar la consolidación de un prejuicio que vincularía la presencia de radiación solar con un elevado riesgo de deslumbramiento. Este objetivo no supone obviar las situaciones en que sí que existe tal riesgo. Los propósitos de la tesis incluyen identificar estas situaciones, analizar sus causas y sugerir las soluciones oportunas.

La tolerancia de la presencia solar en los interiores implica una consecuencia que, por obvia, corre el riesgo de pasar desapercibida. A menudo, el acceso solar está estrechamente asociado a la visión del exterior a través de la ventana. Por tanto, la restricción del acceso solar de manera continuada, por un excesivo temor al riesgo de deslumbramiento o por una falta de dinamismo o flexibilidad en los sistemas de sombreado, implicaría perder la deseada visión del exterior y un gran potencial de iluminación natural. Muchos estudios aíslan el estudio de la ventana como fuente de luz y posible causa de los excesivos contrastes entre el interior y el exterior. En parte, la originalidad de esta tesis es tratar conjuntamente el efecto de la ventana y del acceso solar; ambas superficies brillantes son fuentes de luz y potenciales causas de deslumbramiento.

El segundo objetivo de la tesis es aportar nuevos argumentos para validar los cálculos de deslumbramiento como herramienta para juzgar el buen diseño lumínico de los espacios interiores. Las normas actuales raramente van más allá de la evaluación estrictamente cuantitativa del reparto de la luz incidente (calculada en lux), invisible para los usuarios. Los usuarios perciben la luz cuando ésta es reflejada sobre las superficies (calculada en cd/m2) y juzgan la calidad visual y el confort experimentado en función del contraste entre los diferentes brillos. La formulación de los índices de deslumbramiento, basada en una expresión logarítmica, es fiel a las peculiaridades de la visión humana. No obstante, los ajustes de la formulación y la definición de los límites que juzgan el contraste requieren, todavía hoy, más trabajo para garantizar la fiabilidad de sus cálculos. Los escenarios iluminados con luz solar son oportunos para poner a prueba la formulación ante situaciones caracterizadas por la existencia de contrastes posiblemente extremos.

La tesis afronta un tercer objetivo de tipo metodológico para dar respuesta a los dos objetivos principales anteriormente descritos. El objetivo consiste en programar un “script” (guion de líneas de comandos informáticos) que permita dar respuesta a dos cuestiones técnicas. La primera pone a prueba, en condiciones de luz solar, los rangos de medición que posibilitan las fotografías HDR. La segunda posibilita el trabajo conjunto y comparativo con dos índices de deslumbramiento (DGI y DGP). La metodología pretende dar argumentos para discutir la sensibilidad de estos dos índices ante diferentes escenarios lumínicos motivados por combinaciones diversas: posición del usuario, orientación del espacio, existencia de dispositivos de control de la iluminación y combinación de luz natural y artificial.

1.3 Hipótesis de la tesis

La definición de las hipótesis de trabajo da un paso adelante en aras de la concreción. Reiteradamente, el punto en común de las hipótesis es siempre la consideración de los factores más relevantes en la evaluación del equilibrio lumínico entre las superficies más brillantes («parches de sol»[1] y ventanas) y las restantes superficies más oscuras, consideradas como el fondo visual. El riesgo de deslumbramiento está siempre puesto en tela de juicio. De entre los tres tipos de deslumbramiento, el conocido como molesto está en el punto de mira de todas las hipótesis. Por tanto, los dos otros tipos (deslumbramiento perturbador y por reflexión) quedan relegados a comentarios de menor calibre. En primer lugar, los siguientes enunciados destacan cinco hipótesis generales, ordenadas según su grado de relevancia.

Hipótesis 1: Los parches de sol en un interior suelen ser menos deslumbrantes de lo preconcebido puesto que conllevan un incremento notable de la luminancia del fondo.

La explicación que, *a priori*, validaría esta hipótesis es la siguiente: frecuentemente, la acción conjunta del tipo de acceso solar (impuesto por la orientación del espacio) y de la posición que ocupan los usuarios minimiza el riesgo de deslumbramiento. Aunque los parches solares son superficies con un alto brillo, su posición acostumbra a darse en el perímetro exterior del espacio, cerca de la ventana y lejos del centro de atención de la tarea visual del usuario. Desde esta posición, los parches solares reflejarían la luz y actuarían como segunda fuente luminosa extensa y de notable intensidad, equivalente a la de la ventana. Su efecto aumentaría la luminancia del fondo y, por consiguiente, reduciría el contraste y el riesgo de deslumbramiento. Esta situación es común en las fachadas sur de los edificios ubicados en latitudes europeas que explican la verticalidad de la radiación solar y la frecuente inexistencia de acceso solar en las zonas más profundas de los espacios. Los contextos urbanos favorecen aún más este tipo de acceso solar en los interiores; la radiación solar horizontal tiene menos opciones de penetración a causa de las obstrucciones que provocan las altas densidades urbanas.

[1] En adelante, el término «parche de sol» hará referencia a la presencia solar que se refleja sobre las superficies interiores y exteriores.

Incluso, ante las condiciones descritas, la misma hipótesis podría expresarse de forma más radical y afirmar que la presencia de los parches solares en los interiores mejora el equilibrio lumínico entre el interior y el exterior. La explicación la encontraríamos en la gran diferencia entre las luminancias del exterior y del interior, siendo las exteriores claramente superior. Los parches solares, entendidos como una segunda fuente de luz extensa, demostrarían su efectividad para reequilibrar lumínicamente la visión de la escena.

Hipótesis 2: Los parches de sol presentes en el interior ocasionan un menor grado de deslumbramiento que los que permanecen en el exterior, vistos a través de la ventana.

La explicación que fundamenta esta hipótesis es la siguiente: en estos casos, las superficies deslumbrantes no conseguirían aumentar la luminancia media de unos interiores que permanecen oscuros. El contraste entre la visión brillante del exterior y la oscuridad del interior sería todavía más exagerado y ocasionaría un notable riesgo de deslumbramiento. Los espacios orientados hacia el norte son los más característicos de este tipo de situación. Sin embargo, es menos frecuente que los estudios de deslumbramiento presten atención a estos casos.

Hipótesis 3: Cuando los parches solares ocupan posiciones profundas dentro de los espacios, su efecto no es el causante de los grados de deslumbramiento más agudos. La previsible visión del sol y de su halo es la causa principal de este tipo de molestia.

Diferentes aspectos validarían la formulación de esta hipótesis: en primer lugar, la fuerte inclinación de los rayos solares no ocasionaría unos valores de luminancias extremos. En cambio, su contribución elevaría la luminancia media de la escena. Por consiguiente, los parches solares pasarían a formar parte de la luminancia del fondo y dejarían de ser considerados como superficies deslumbrantes. La situación sólo sería crítica cuando el acabado de las superficies interiores fuese de tipo especular. En estos casos, sólo una pequeña parte de los parches solares, la correspondiente al reflejo de la circunferencia solar, sería la causante de molestia. Este caso sólo se daría en momentos puntuales, en los que los usuarios encarasen el reflejo. Sin embargo, ante tal situación, más que la visión del reflejo, lo verdaderamente molesto sería la propia aparición del sol y de su halo dentro del campo visual. Con lo cual, en estos casos, la causa del deslumbramiento no sería tanto la presencia de los parches solares en los interiores como la visión de altas luminancias del cielo a través de la ventana. Dicho de otro modo, la molestia no estaría ocasionada por los desequilibrios lumínicos (deslumbramiento molesto), sino más bien por la incapacitación que causa la visión de una luz excesiva dentro del campo visual (deslumbramiento perturbador).

Hipótesis 4: El riesgo de deslumbramiento es notablemente mayor cuando los usuarios ocupan posiciones frontales respecto a las ventanas.

El deslumbramiento es un parámetro vinculado a la visión de los usuarios. Por tanto, no sólo depende de la posición del parche de sol dentro (o fuera) del espacio. La posición del usuario es asimismo fundamental. Dos tipos de posiciones son habituales en los espacios: frontales o laterales respecto a la ventana. Claramente, las posiciones frontales son las más críticas en términos de deslumbramiento. Dos motivos justifican esta hipótesis. Primero, el deslumbramiento es menor cuando la visión de las superficies brillantes ocupa la periferia del campo visual. Adecuándose a ello, la formulación del deslumbramiento incorpora un coeficiente de posición sensible a esta característica visual. Segundo, desde las posiciones frontales, a cierta profundidad dentro del espacio, predomina la visión de las superficies más oscuras (techo, suelo y paredes laterales). Si esta hipótesis se confirma, la solución para disminuir el riesgo de deslumbramiento es sencilla: evitar disposiciones del mobiliario que supongan visiones frontales de las ventanas.

La propia expresión de la formulación de los índices de deslumbramiento anticipa esta última hipótesis ya que contiene un coeficiente de posición cuya misión es minimizar el impacto de las superficies brillantes que ocupan posiciones periféricas dentro del campo visual. Sin embargo, conviene proceder con la evaluación de los casos de estudio para comprobar experimentalmente la ponderación de los resultados a través de dicho coeficiente.

Hipótesis 5: El índice de deslumbramiento DGI es más fiable que el DGP si el objetivo es describir el equilibrio de la luz natural.

Esta última hipótesis general aborda la fiabilidad de los índices de deslumbramiento en función del tipo de escena lumínica. El índice DGP aparenta estar más relacionado con el deslumbramiento causado a una excesiva cantidad de luz (un valor alto de Ev). Sin embargo, el índice DGI parece estar más vinculado con la visión del contraste lumínico entre el interior y el exterior o, dicho de manera más genérica, entre las superficies más brillantes (incluyendo los parches de sol) y el fondo que las contiene. Esta última hipótesis general también la sugiere la propia expresión matemática de las fórmulas correspondientes a estos dos índices de deslumbramiento. De nuevo, los casos de estudios servirán para verificar en qué medida es cierta esta hipótesis.

Las cuatro hipótesis siguientes consideran la eficiencia de los dispositivos de regulación de la luz que participan en el control deslumbramiento. Más adelante, los casos de estudio pondrán a prueba a su validez través de la introducción de ciertas variables que permitirán deducciones comparativas.

Hipótesis 6: El potencial de la iluminación artificial es insuficiente para corregir los desequilibrios causados por la luz natural.

A menudo, ante la presencia de un excesivo contraste lumínico entre el interior y el exterior, los usuarios encienden la luz para contrarrestar la aparente carencia de luz en el interior. Sin embargo, esta contribución es insuficiente. Los dispositivos de iluminación artificial acostumbran a dirigir la luz hacia las mesas, sobre las cuales se requieren ciertos niveles de luz para el desarrollo de las tareas visuales. Su contribución en el incremento de la iluminación de las paredes es baja. Habitualmente, las paredes son muy aparentes dentro del campo visual de las miradas horizontales que juzgan la iluminación general de los interiores. Si su luminancia baja, la luminancia media del fondo también corre el riesgo de ser demasiado baja como para contrarrestar el desequilibrio causado por las altas luminancias de las fuentes de deslumbramiento.

Hipótesis 7: Si las ventanas son pequeñas, el riesgo de deslumbramiento es mayor que cuando son grandes o muy grandes.

En presencia de grandes ventanas, la visión del cielo y la presencia de los parches solares aumentan la luminancia media de la escena. Este efecto compensa el contraste entre el interior y el exterior. No ocurre lo mismo cuando las ventanas son pequeñas. La aportación del cielo y de los parches solares es insuficiente para compensar lumínicamente la escena. El interior permanece oscuro en relación al alto brillo del cielo y de los parches solares.

Hipótesis 8: En condiciones de luz solar, el riesgo de deslumbramiento varía poco a lo largo de un día o dentro de una misma estación cuando el espacio está orientado a sur o a norte. La situación es menos constante en espacios orientados hacia el este u oeste.

La lectura de una carta solar estereográfica justifica la formulación de esta hipótesis. La comparación de unos días con otros dentro de una misma estación permite identificar que los recorridos solares son bastante similares. Por tanto, las posiciones que ocupan los parches solares dentro del espacio registran pocos cambios dentro de una misma estación. La situación también es bastante estable para las fachadas norte y sur a lo largo de las diferentes horas de un mismo día. La situación es diferente para las fachadas este y oeste. Los rápidos cambios de la posición del sol durante el amanecer y el atardecer provocan variaciones constantes en la posición de los parches solares que ocasionan alteraciones en el riesgo de deslumbramiento. Igualmente, la incidencia solar sobre estas últimas fachadas es muy diferente si comparamos el recorrido solar de verano y de invierno. El diseño de los dispositivos de sombreado es especialmente crítico en estas fachadas.

Hipótesis 9: En las fachadas este y oeste, las cortinas enrollables procuran un mejor control del deslumbramiento que las persianas enrollables y las lamas verticales.

La hipótesis anterior hace referencia a los rápidos cambios que registra la altitud y el azimut solar a lo largo de las horas en que la radiación incide sobre las fachadas este y oeste. Estos cambios obligan a un accionamiento continuo de la posición de las persianas y las lamas si el objetivo es lograr el control del deslumbramiento sin provocar una excesiva oscuridad en el interior. Sin embargo, las cortinas permiten la transparencia. Desde que inicia la incidencia solar, las cortinas pueden cubrir la totalidad de la ventana. Un buen diseño de su grado de transparencia permite una cierta visión del exterior, minimiza el acceso solar, provoca una transmisión difusa de la luz y finalmente, reduce notablemente el grado de deslumbramiento.

1.4 Estructura de la tesis

Seis capítulos estructuran el desarrollo de la tesis (figura 1.1). El **capítulo 1** presenta y define la tesis justificando el tema y exponiendo los objetivos a alcanzar y las hipótesis de partida.

Los capítulos 2 y 3 presentan los antecedentes y las bases de esta investigación. En el **capítulo 2**, una revisión bibliográfica pone en valor la presencia de la luz solar en los interiores. El testimonio de fotógrafos profesionales especializados en arquitectura describe el interés de las experiencias visuales. Los trabajos científicos destacan la predilección que sienten los usuarios por la presencia de la luz solar e informan de sus efectos saludables. Un recorrido por la historia descubre las obras y las normas que son muestras ejemplares de un conveniente diseño lumínico. Pese a ello, la legislación actual muestra carencias cuando únicamente afronta aspectos cuantitativos (reparto de niveles lumínicos mínimos). Los aspectos cualitativos (interés vinculado a la visión de la luz) deberían formar parte del diseño más a menudo. El reto implica dotarse de herramientas de evaluación del equilibrio de la luz visible en los espacios.

El **capítulo 3** centra la atención en los índices de deslumbramiento cuyo propósito es advertir si un contraste lumínico es excesivo. La dificultad es notable ya que estos índices pretenden prever la reacción de la percepción visual, parcialmente subjetiva. Las tentativas para validar los índices son numerosas. Este capítulo analiza ocho índices de deslumbramiento y escoge dos para introducirlos en una metodología de evaluación basada en la lectura de imágenes HDR.

El **capítulo 4** presenta los detalles de la metodología de trabajo. El desarrollo de un “script” permite encadenar procedimientos informáticos que aprovechan herramientas de Radiance, Webhdrtools y Evalglare para analizar en riesgo de deslumbramiento en las escenas retratadas a través de imágenes HDR. La metodología incluye la valoración de la repercusión de diferentes parámetros de calibración propios de la cámara (centro del horquillado) y de las instrucciones de cálculo (factor de calibración y umbral de definición de la fuente deslumbramiento) para garantizar la fiabilidad de los cálculos en condiciones de luz solar.

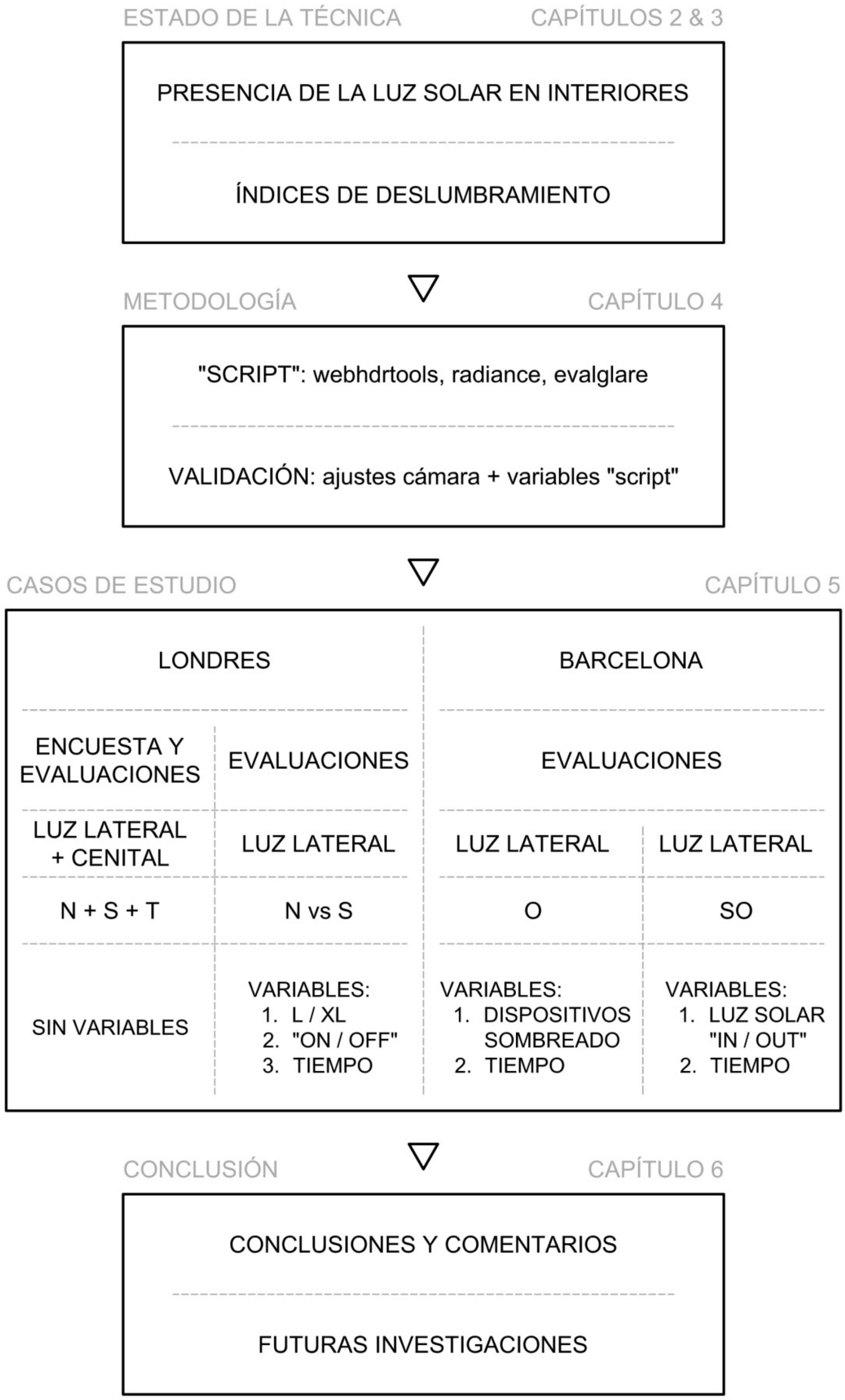

Fig. 1.1. Estructura de la tesis

El **capítulo 5** presenta las condiciones, los resultados, los comentarios y las conclusiones parciales de cada experimento. Las mediciones suceden en verano, en interiores diversos ubicados en dos ciudades. En Londres, el primer caso considera una oficina singular, con luz cenital y lateral (dos fachadas). La obtención de resultados es comparada con la percepción de unos observadores de nacionalidades y culturas lumínicas distintas. A continuación, dos salas de reunión permiten evaluar la percepción de un notable número de campos visuales. La orientación opuesta de las salas (norte y sur) sirve para comparar los efectos de la presencia solar en el interior o en el exterior. En ambos casos, dos variables son incorporadas: el tamaño de ventana y la contribución de la iluminación artificial. En Barcelona, dos otras salas de reunión son analizadas, ambas con penetraciones solares más profundas a causa de su orientación oeste. Esta particularidad da lugar a la consideración de los efectos de diferentes dispositivos de control de la luz solar: persianas, cortinas enrollables y lamas verticales. Finalmente, en Barcelona, un último caso sirve para juzgar un espacio con condiciones distintas a las anteriores, caracterizado por una proporción de ventana pequeña en relación a la totalidad de la fachada y por una orientación suroeste que, según la hora del día, alterna la presencia solar en el interior y en el exterior.

Finalmente, en el **capítulo 6,** los resultados de los casos de estudio dan lugar a conclusiones específicas en función del tipo de penetración solar (motivado por las diferentes orientaciones), de la posición que ocupan los usuarios y de los dispositivos de control utilizados. Las conclusiones específicas dan respuesta a las hipótesis de partida. Además, su contribución conjunta permite dictaminar en qué situaciones la presencia solar genera iluminaciones interiores excesivamente desequilibradas que podrían causar el deslumbramiento de los usuarios. En última instancia, el capítulo 6 sugiere nuevos procedimientos experimentales que darían mayor respaldo a las conclusiones de esta tesis y otras alternativas que posibilitarían nuevos enfoques.

A continuación de los capítulos, dos apéndices son adjuntados. El **apéndice A** presenta el cuestionario que fue utilizado para el desarrollo de los primeros casos de estudio que cotejan las respuestas de los usuarios y los resultados de los cálculos de deslumbramiento. El **apéndice B** incluye dos publicaciones llevadas a cabo durante el período de la tesis. La primera (PLEA 2011) considera los efectos térmicos de la luz solar (en verano y en invierno) para recomendar opciones de diseño; su contribución complementa el trabajo de esta tesis, cuyo contenido está únicamente centrado en los efectos lumínicos de la luz solar. El segundo artículo (WREF 2012) considera la evaluación del deslumbramiento en escenas con iluminación natural; su objetivo es determinar la repercusión que tendría sobre los resultados el uso de dos funciones distintas para ponderar el efecto de las luminancias según la posición que ocupan dentro del campo visual del observador. Esta cuestión está claramente vinculada con el contenido de esta tesis.

Capítulo 2: La presencia de la luz solar en los espacios interiores

Chapter 2: The presence of sunlight in indoor spaces

At the beginning of the thesis, the note to the reader mentions that this second chapter has been written in Spanish. Below, the English translation of its introduction (subchapter 2.1) provides a summary of its content:

*The aim of this chapter is to highlight multiple viewpoints that describe, from different perspectives, the presence of sunlight in interiors. The investigation begins with an initial subchapter (2.2) that contains the testimonies of specialized photographers in architecture. In 2010, the Spanish photography magazine, named EXIT, dedicated two issues specifically to photography. The first, entitled "*Architecture I. The professional look*", presents a sample of the work of photographers of international standing. Each of the photographers accompanies a selection of their pictures with a text in which they explain their points of view about their profession. Obviously, many photographers find inspiration in the essence of the spaces they portray and in the light that gives them definition. The photographers' attentive gaze, translated into images and words, serves as a starting point to underline what, daily, the users of the spaces see and perceive instinctively, without stopping time to portray it in a photograph.*

In the next subchapter (2.3), researchers specialized in daylighting take over. Scientists are no strangers to the artistic work of photographers. The perception of the users is again the topic of discussion. As will be seen, the key motivating factor of the researchers' contributions is closely linked to the appreciation of the photographers. Beyond paying attention to the quantitative aspects of daylighting, their fixation is to stress the qualitative aspects. The researchers highlight that users require the presence of sunlight in interiors because it connects them to their surrounding environment. Their margins of comfort seem to increase in the presence of sunlight, which is welcomed into the interiors despite the greater potential for visual and thermal *extremes within the same space. Much of the researchers' work justifies statistically the users desire for interiors to be lit naturally, utilising sunlight, and their work also argues that such desires demonstrate the clear physical and mental benefits that sunlight brings to the users.*

After describing the particularities of the perception of sunlight in interiors, the following subchapter (2.4) moves the discussion to the field of design. The aim is to describe the relevance of sunlight in the aesthetic and functional lighting of spaces. A journey through history is useful to recognize the milestones of the design and to identify the standards and recommendations that have accompanied and guided them. Arriving in the contemporary context, the subchapter also summarises the legislative landscape governing the newest design, and identifies the limitations of these documents. Finally, this last subchapter gives importance to the recent investigations that propose new alternative methods of assessing the presence of sunlight and, giving them continuity, demarcates the contribution of this thesis.

2.1. Introducción

La vocación de este capítulo es subrayar múltiples puntos de vista que describen, desde prismas diferentes, la presencia de la luz solar en los interiores. El recorrido propuesto comienza con un primer subcapítulo (2.2) que recoge el testimonio de los fotógrafos especializados en arquitectura. En 2010, la revista española EXIT dedicó dos números a su fotografía. El primero, titulado *Arquitectura I. La mirada profesional*, presenta una muestra del trabajo de fotógrafos de prestigio internacional. Cada uno de los fotógrafos acompaña la selección de sus imágenes con un texto en el que explica su punto de vista sobre su profesión. Como es lógico, muchos fotógrafos encuentran la inspiración en la esencia de los espacios que retratan y en la luz que los ilumina. Su mirada atenta, traducida en imágenes y en palabras, sirve de punto partida para subrayar lo que cotidianamente los usuarios de los espacios ven y perciben instintivamente, sin detener tiempo para retratarlo en una fotografía.

En el siguiente subcapítulo (2.3) los investigadores especializados en luz natural toman el relevo. Los científicos no son ajenos al trabajo artístico de los fotógrafos. La percepción de los usuarios vuelve a ser el tema de discusión. Como se verá, la esencia de las contribuciones de los investigadores está íntimamente ligada con la apreciación de los fotógrafos. Más allá de prestar atención a los aspectos cuantitativos de la luz natural, su fijación está puesta en destacar los aspectos cualitativos. Los investigadores ponen de manifiesto que los usuarios requieren la presencia de la luz solar en los interiores porque les pone en relación con el medioambiente que les rodea. Sus márgenes de confort parecen ampliarse ante la presencia de la luz solar que es bienvenida en los interiores pese a los excesos lumínicos y térmicos que pueda suponer. Gran parte del trabajo de los investigadores justifica estadísticamente el deseo de luz solar en los interiores y, además, argumenta que dicho deseo atiende al beneficio físico y psíquico que la luz solar aporta sobre los usuarios.

Tras describir las particularidades de la percepción de la luz solar en los interiores, el siguiente subcapítulo (2.4) traslada la discusión al ámbito del diseño. El objetivo es describir el protagonismo de la luz solar en la iluminación estética y funcional de los espacios. Un recorrido por la historia es de utilidad para reconocer los hitos del diseño y para dar a conocer las normas y las recomendaciones que los han acompañado y pautado. Situándose en la actualidad, el subcapítulo resume el panorama legislativo que rige el diseño más reciente e identifica las limitaciones de estos documentos. Finalmente, este último subcapítulo (2.4) concede el protagonismo a las investigaciones que proponen nuevas alternativas para valorar la presencia de la luz solar y, dándoles continuidad, enmarca la contribución de esta tesis.

2.2. Experimentar la luz solar: la mirada fotográfica del usuario

La tesis comienza citando un diálogo de *Down by Law*, una película de Jim Jarmusch del año 1986, cuyo guion fue escrito en 1985 (Jarmusch, 1985). La introducción a la película es un largo travelín por las calles más sórdidas de New Orleans, mientras suena la música de Tom Waits. El paseo queda interrumpido por una escena en una de esas casas. Jack se levanta de su cama y acude al porche donde encuentra a Julie, balanceándose sobre una mecedora. Él le pregunta a ella: “Julie, what are you doing here”. Y, ella le responde: “Just watching the light changing”. Sin decir más, Jack vuelve a su cama, se reanuda la música y el travelín por New Orleans. La intervención de Julie guarda una estrecha relación con el contenido de este capítulo. En un momento de calma, con la mirada perdida en el paisaje y en sus pensamientos, Julie sorprende al espectador con la sensibilidad de su comentario. Su mirada parece algo más que un sencillo mirar. Su mirada entiende, bajo una perspectiva propia, da sentido a lo que ve. O, visto desde otro prisma, lo que ve cobra sentido en relación a lo que piensa. Como ella dice, está viendo la luz y su cambio al transcurrir el tiempo. A través de su calmada intervención, el espectador puede imaginar la serenidad que transmite la luz que modela un paisaje urbano que, por momentos, le parece menos decrépito de lo que realmente es. Además, atendiendo a sus palabras, la luz está cambiando, lentamente claro está, pero uno diría que si la mira con atención puede ser testigo del cambio y presenciar lo invisible, lo que algunos temen: el pasar del tiempo.

¿Está Julie presenciando un momento especialmente mágico en un entorno de diseño atractivo que le sugiere la reflexión? Nada más lejos de la realidad. Las deprimentes calles de un New Orleans empobrecido, iluminadas bajo el sol de justicia de una mañana tórrida, no parecen el entorno más sugestivo. Pero a la mirada atenta que congela el tiempo, la serenidad que transmite la luz natural no le pasa desapercibida. ¿No es esa la característica mirada de un fotógrafo? ¿No es por definición el fotógrafo la persona que ostenta el poder de parar el tiempo y contemplar cómo la luz revela el entorno? Así es, aunque no es el único. En cambio, sí que es el único que anda equipado con una cámara preparada para retratar, cuya vocación es explicar a terceros la experiencia en un lugar. Pero su mirada, o más bien su cámara si consideramos ya la imagen retratada, no ve más que aquel que estuvo allí. De hecho, si solo tuviésemos en cuenta la capacidad óptica de la cámara, podríamos decir que el fotógrafo ve menos. El ángulo de visión que le proporciona el objetivo es normalmente menor al de la visión humana. Lo mismo sucede con el rango lumínico que puede percibir. Su única baza es la atención con la que mira y retrata, armada de paciencia, con el fin de descubrir a conciencia lo que el ocupante del espacio presencia inconscientemente, sin detenerse en los detalles. A continuación, los fotógrafos de arquitectura toman la palabra para subrayar el significado de lo que los usuarios ven cuando la luz solar hace acto de presencia en los interiores.

En los años 2009 y 2010, la revista española de fotografía EXIT publicó dos números dedicados al retrato de la arquitectura: *Arquitectura I. La mirada profesional* y *Arquitectura II. La mirada del artista*. Como los títulos dejan entrever, la amplitud de su propósito no focaliza en la luz natural, y menos aún en la luz solar. Sin embargo, los ejemplos que retratan la arquitectura bajo los efectos de la luz artificial son pocos. Uno diría que retratar la arquitectura bajo los efectos de la luz natural sigue formando parte de un pacto no escrito para juzgar la calidad de los proyectos. ¿Cuál es el motivo? Ante el desafío de entender, y después retratar, los fotógrafos pretenden ser fieles a las ideas de los arquitectos que proyectaron los espacios. Sabedores de que sus autores a menudo conciben sus interiores iluminados con luz natural, los fotógrafos evitan contaminar sus fotografías con aportes lumínicos ajenos a la idea retratada. A menudo renuncian a la iluminación artificial existente, propia del espacio, y consideraran una falta de sinceridad completar sus fotografías con luz de relleno.

La comentada pretensión de entender lo retratado está presente en los textos de los fotógrafos que desvelan los secretos de sus fotografías. La fotógrafa suiza Hélène Binet dice al respecto (Binet, 2009):

> Comencé a utilizar la fotografía para comprenderlas —las obras de arquitectura—. He procurado siempre mantener este elemento de investigación en mis fotografías. Intentar entender, no simplemente representar.

Fig. 2.1. **Hélène Binet**[1]. *LF one*, Weil am Rhein, Alemania, Zaha Hadid

[1] Fuente: Binet, H, (2000). *Architecture of Zaha Hadid in photographs by Helen Binet*. Baden: Lars Müller Publishers. ISBN: 3907078128

Erza Stoller es uno de los más famosos retratistas de la arquitectura moderna. Suyas son las fotografías de los proyectos más emblemáticos de Mies Van der Rohe, Le Corbusier, Eero Saarinen y tantos otros. De entre sus imágenes de interiores, las de la terminal área de la TWA en Nueva York (1962) y las de la capilla de Ronchamp (1955) son pruebas manifiestas de la fascinación que sintieron los arquitectos del Movimiento Moderno por la amplitud espacial de unos interiores que proporcionan un estrecho contacto visual y lumínico con los exteriores. Cuántas veces habrá escuchado un estudiante de arquitectura educado bajo los preceptos del Movimiento Moderno, en boca de su profesor, el siguiente comentario: “deberías garantizar la continuidad espacial entre el interior y el exterior”. Pues bien, *The Yale architectural Journal* publicó en 1963 un artículo de Erza Stoller. Respecto a los propósitos de la fotografía arquitectónica, Stoller también destacaba la importancia de entender el significado de los interiores y, más concretamente, las ideas de los arquitectos que los proyectaron. Algunos de los extractos de su artículo (Stoller, 1963), traducidos al castellano, indican lo siguiente:

> […] estoy convencido de que sólo existe una clase de fotografía arquitectónica, y que es aquella que transmite la idea del arquitecto […]. La mayoría de nosotros deberíamos contentarnos con no ser críticos. Supongamos que el espectador posee su propia inteligencia y facultades, y que no quisiera más que alguna información no distorsionada en la que basar sus propias conclusiones. […] Luego, dadas la apreciación, la compresión y la imaginación necesarias, es posible experimentar de primera mano el placer personal de percibir una idea.

En el mismo texto, Erza Stoller aborda la cuestión de las limitaciones gráficas de la imagen fotográfica que son más restrictivas que las capacidades del supuesto usuario que presenciaría los espacios. Stoller dice al respecto:

> En cuanto al mismo medio, está lejos de ser una herramienta perfecta. El espectro de luz que puede recoger una lámina de película es limitado y queda muy por debajo de lo que el ojo puede asimilar; y llegado el momento en que la imagen queda impresa en un trozo de papel, este espectro se ha reducido todavía más. Para recortar esa discrepancia, a menudo debe añadirse luz al objeto, lo que tiende a destruir el ambiente del espacio.

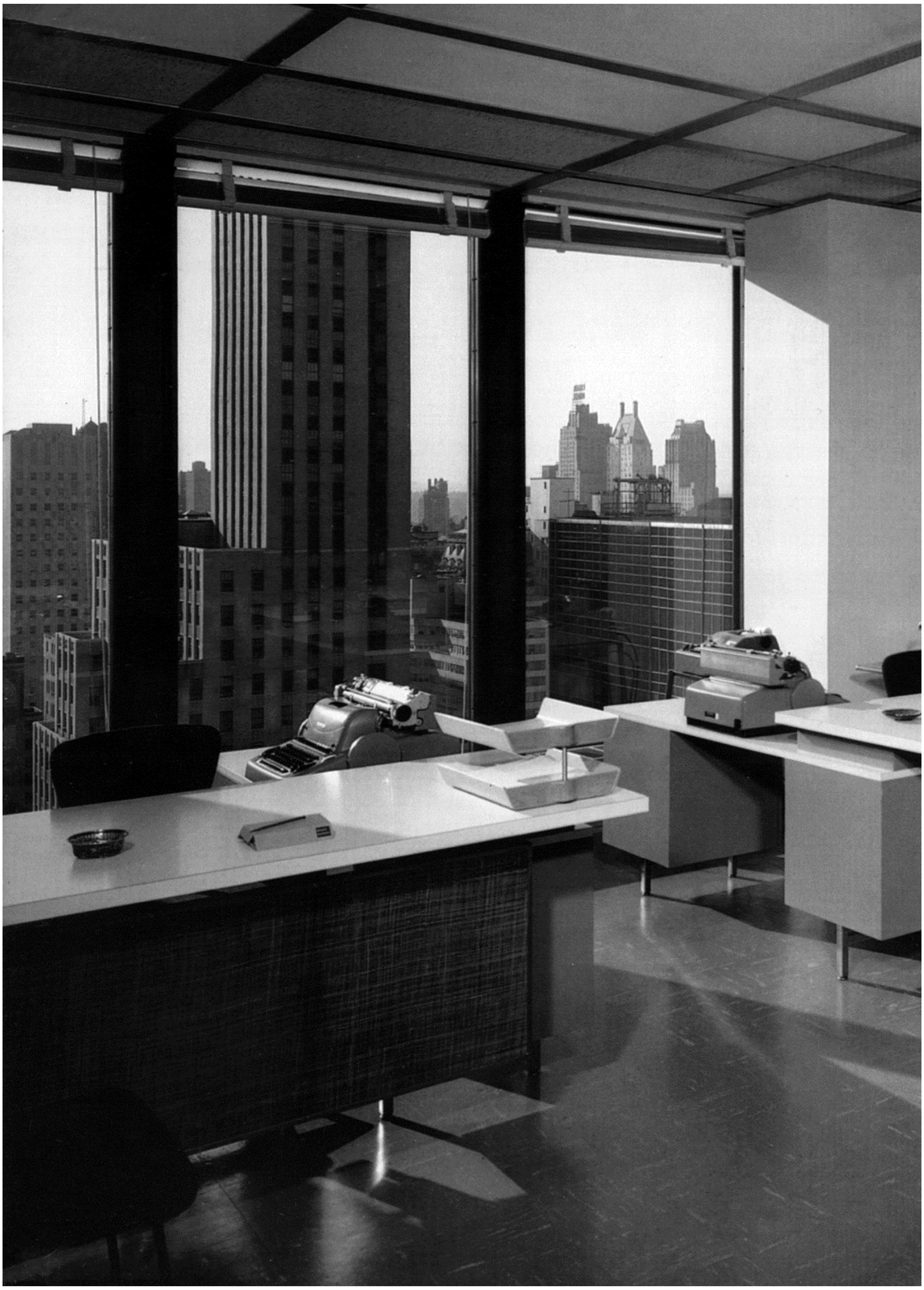

Fig. 2.2. **Erza Stoller**[2]. *The Seagram Building*, New York, EUA. Mies van der Rohe, 1958

[2] Fuente: Stoller, E. (1999). *The Seagram Building*. New York: Princeton Architectural Press. ISBN: 1568982011.

Norman McGrath es autor del libro *Photographing Buildings Inside an Out* (McGrath, 1993) que fue publicado en 1988 y revisado por él mismo en 1993. El texto publicado en EXIT hace énfasis en su preocupación por las limitaciones de la fotografía ante los contrastes que un usuario experimenta en un interior en contacto visual y lumínico con un exterior. Suyas son las palabras que sugieren que las iluminaciones suplementarias a la luz natural son una artimaña que resta valor a la fotografía. McGrath lo dice de la siguiente manera:

> Incluso en la época pre-digital, era un gran defensor del método sutil de iluminar interiores. Raramente he utilizado iluminación adicional directa, y cuando un espectador de mi obra acabada me preguntó si había añadido iluminación o no, sentí que había triunfado. Con la llegada del método del HDR (high dynamic range) para captar interiores ya puedo abarcar situaciones de gran contraste sin añadir iluminación.

Lluís Casals es uno de los fotógrafos más relevantes del contexto español. Él es el retratista de las obras de algunos de arquitectos españoles de más prestigio. Moneo, Vázquez Consuegra, Tuñon, Mansilla, Bohigas, Bonell y tantos otros aparecen en su listado de clientes. Las palabras de su texto en EXIT (Casals, 2009) explicitan su sensibilidad como fotógrafo. A través de ellas, Casals da prueba manifiesta de la preocupación que comparte con los fotógrafos mencionados anteriormente en cuanto al reto de compresión que implica el retrato espacial. Además de señalar dicho reto, sus reflexiones dan más detalle en cuanto a la dificultad de trasladar sobre un papel la experiencia visual vivida. El usuario que experimenta la plenitud de un espacio goza de dos ingredientes fundamentales que aquel que contempla una imagen no puede saborear más que a través de la destreza del fotógrafo que se las ingenia para minimizar el sinsabor de su carencia. El primer ingrediente puede desdoblarse en dos: la capacidad de movimiento en el interior y la pluralidad de la dirección de su mirada. La conjunción de ambos permite al usuario construirse mentalmente una imagen inequívoca de las características tridimensionales de un espacio. El segundo ingrediente hace referencia a lo que la física denomina la cuarta dimensión, el tiempo. El usuario que convive asiduamente con un espacio es sensible a los efectos que el tiempo implica. Las tareas cotidianas no siempre permiten reservar espacios temporales para reparar cómo se transforma un espacio a lo largo del tiempo bajo los efectos de la luz natural que lo transita revelando el volumen, las texturas y el color de

Fig. 2.3. **Erza Stoller**[3]. *TWA Terminal*, New York, EUA, Eero Saarinen, 1962

[3] Fuente: Stoller, E. (1999). *The TWA Terminal*. New York: Princeton Architectural Press. ISBN: 1568981821

las superficies. Que no se detenga en la contemplación no significa que el usuario no sea sensible a lo que sucede. La luz y su cambio constante, diario y estacional, sensibiliza al ocupante de un interior sobre los ritmos vitales que le son propios y que experimenta sin límites en el exterior. Ser testigo de esos cambios es una necesidad de la que un usuario no puede prescindir. El trabajo de los investigadores científicos dará prueba manifiesta de ello en los siguientes subcapítulos. Pero antes de abordar su contribución, el trabajo de los fotógrafos y sus comentarios propios sigue dando muchas pistas sobre el mirar de un usuario sintetizado a través de la mirada de un fotógrafo. Lluís Casals ha servido para introducir muchos de los conceptos expresados en este párrafo. Sus propias palabras (Casals, 2009) sirven de colofón respecto al propósito de la fotografía y cómo el fotógrafo lidia para transmitir la riqueza de la experimentación de un espacio:

> Un reto en el que tengo que descubrir y comprender la razón de un volumen en el espacio para darlo posteriormente a conocer a través de otra forma, en este caso, dentro de los límites de un rectángulo. Es apasionante. Un juego que, a partir de las decisiones formales de otra persona —el arquitecto— me lleva a entrar en sus razones, sus influencias, sus pasiones y también sus “manías”. Disfruto leyendo en las paredes y en el paisaje: el qué, el cómo y el porqué de un edificio. Transformar esta información en una geometría plana mediante la línea, la composición y la luz, es un placer. Es como escribir, pero con otro abecedario. […] Es un trabajo que me permite practicar la contemplación a todas horas. Un oficio en el que puedo ver los atardeceres y ser testigo de las cosechas. Y, además, me da el aire.

Las afirmaciones de Casals dejan claro su gusto por el reto al convertir las limitaciones técnicas gráficas que conlleva la fotografía en virtudes artísticas. No obstante, deja claro que parte del placer se debe al privilegio de experimentar el espacio como lo haría un usuario. Hélène Binet también expresa lo fundamental que es la experiencia del espacio. A diferencia de Casals, sus palabras (Binet, 2009) ponen más énfasis en la dificultad que conlleva un reto, a su entender, irresoluble con una única fotografía:

> La experiencia de la arquitectura es muy compleja (“Eres devorado por un edificio” - John Hejduk). Es algo que no puede ser representado en una sencilla fotografía. A lo largo de los años he intentado alejarme de la visión general, tradicional, glamurosa y colorida de un edificio que intenta expresarlo todo, pero que en mi opinión, se sitúa muy

Fig. 2.4. **Lluís Casals**[4]. *Salón de Comares*. La Alhambra, Granada, España

[4] Fuente: Casals, L. (2000). *La Alhambra de Granada*. Granada: Patronato de la Alhambra y Generalife; Menorca: Triangle Postals. ISBN: 8489815747

> lejos de los que es experimentar el edifico. Mi interés está en imágenes en blanco y negro, muy específicas y reducidas. El fin es comunicar, por ejemplo, algo de lo que se siente al estar en el espacio. El color es uno de los muchos elementos que se experimenta de un edificio, así como el volumen, la función, la luz, los detalles, etc. Usar el blanco y negro me permite enfocar con más claridad estos elementos. Creo que una serie de fotografías es una manera lograda de articular algo de la experiencia que se tiene al estar dentro del edificio.

Erza Stoller (1963) también aborda la cuestión de las limitaciones de la representación fotográfica en comparación a la experiencia visual total que incluye la profundidad, el tiempo y el color. Sus palabras contienen cierta resignación y aceptan que lo máximo a que se puede aspirar es conseguir cierta impresión, nunca exacta, de la experiencia completa:

> […] cuanto esperamos lograr es una impresión —y ésta rara vez es exacta. […] Queda claro que el éxito de quien trabaja en cualquier medio se mide por su capacidad de convertir sus limitaciones en activos, expandiendo dicho medio e incrementando su versatilidad. […] La calidad de la luz, la perspectiva, el punto de vista, la relación con otros objetos, el instante de la exposición, la distorsión o la falta de la misma, el color -todo puede manipularse al servicio de una amplia variedad de fines, y los resultados se juzgarán por el uso de que se dé de estas características.

Un texto que pretenda establecer paralelismos entre la mirada fotográfica y la mirada del usuario no puede obviar la opinión de Julius Shulman, otro de los grandes fotógrafos de la modernidad arquitectónica del siglo XX. Su testimonio es especialmente relevante porque concede parte del protagonismo a los ocupantes de las casas que aparecen retratados posando en los interiores. Cabe recordar algunas de sus fotografías emblemáticas de las Case Study Houses número 21 y 22, ubicadas en Los Angeles. En ellas, los figurantes, tan apuestos como los actores de Hollywood, hacen uso de unos interiores rabiosamente modernos, tanto en su definición espacial como en su decoración. Shulman no se limita a escenificar la vida en los interiores. Su interés también atiende a sugerir como se viven los jardines y las piscinas que rodean las casas modernas. Su fotografía de la Case Study House número 20 retrata cómo una mujer disfruta de su copa en bañador, junto al borde de la piscina, ante la distraída mirada de su acompañante quien, lejos de admirar la escena, lee una revista. Más allá

Fig. 2.5. **Julius Shulman**[5]. *Eames House*, Pacific Palisades, EUA, Charles Eames, 1958

[5] Fuente: Shulman, J. (1998). *Architecture and its photography*. Köln [etc]: Taschen. ISBN: 3822872040

de ciertos clichés que escenifican los figurantes, lo relevante es que la representación fotográfica del espacio da cabida a muchos de los atributos mencionados anteriormente. Julius Shulman concedió una entrevista en 1990 en la que cuenta la historia de la fotografía del año 1947 de la casa Kaufmann en Palm Springs de Richard Neutra. Explica lo siguiente:

> Lo único que sabía es que era una cosa preciosa y que iba a intentar capturar todos los elementos del diseño, junto con el ambiente de las montañas, el crepúsculo, la magia.

Una vez más, el comentario revela la voluntad del fotógrafo de plasmar en la fotografía la experiencia privilegiada, vivida por él mismo, al estar allí. La experiencia mágica sucede ante la llegada del ocaso, cuando la caída del sol y la luz que le acompaña se hacen más evidentes. En esos últimos instantes del día, el paisaje y la arquitectura, aunque ideada por Neutra, pasan a ser el telón de fondo de la mirada y la fotografía dirigidas hacia el horizonte. En esa dirección, la mirada admira cómo se apaga la prodigiosa luz solar consumiendo no ya la luz solar, que volverá al día siguiente, sino el tiempo que nunca volverá.

¿Hay algo más evocador que una mirada que siente el tiempo pasar? Vinicius de Moraes recuerda otra experiencia igualmente evocadora en la que, con sorpresa, a través de otra mirada dirigida hacia el horizonte, sintió la tierra rodar. Así lo explica en su introducción a la canción *Tarde em Itapoa* cuando describe el momento en que la canción fue compuesta en una tarde, como dice él, de total vagabundaje por la playa de Bahía:

> Es una canción que habla de un día, de una tarde, en la que paseábamos Toquinho y yo por esta playa, en “shortes” de baño, chupando una “cachacita”, sí, a veces bebiendo un agua de coco, y después, con la mirada perdida en el encuentro entre cielo y mar, parece que sentimos toda la tierra rodar.

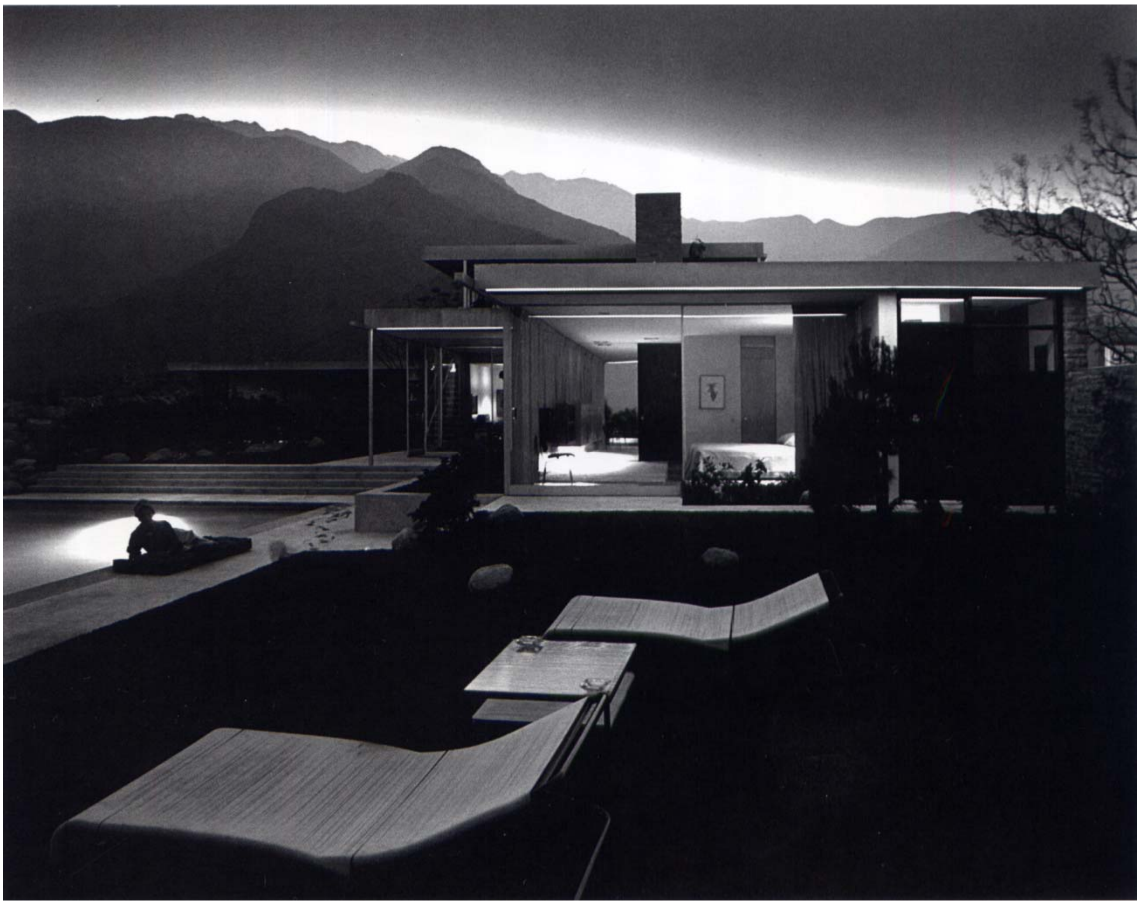

Fig. 2.6. **Julius Shulman**[6]. *Kaufmann House*, Palm Springs, EUA, Richard Neutra, 1947

[6] Fuente: EXT Imagen y cultura (2009). *36 Arquitectura I. La mirada profesional*. Madrid: Olivares y Asociados. ISSN 15772721.

2.3. Los usuarios y su deseo de luz solar en los interiores

Alain Corbin dirigió en el año 2013 la publicación de un libro de historia titulado *La pluie, le soleil et le vent. Une histoire de la sensibilité au temps qu'il fait*. En éste, diferentes autores tejen significados a partir de las obras que otros publicaron a lo largo de la historia. Christophe Granger es el autor del capítulo dedicado al sol que titula *Le soleil, ou la saveur des temps insoucieux*. Dos de las citas que utiliza para construir sus argumentos están íntimamente ligadas con los dos ejes que estructuran este capítulo. En primer lugar, haciendo uso de las palabras que Pierre Bailly[7] publicó en 1628, Granger enuncia lo indispensable que es la presencia solar:

> « […] la présence du soleil, quand elle est d'une juste distance, non seulement pour la clarté, mais aussi pour la chaleur », est indispensable à la vie. « Car sans elle tout serait mort au monde. C'est le siège de la vie. Aussi Dieu l'a-t-il mis au milieu du monde, au milieu des cieux, pour vivifier et illuminer toute chose, comme le cœur fontaine de chaleur a été posé au milieu du corps pour y avoir sa chaleur vivifiante. »

Este argumento, que recalca la importancia de la presencia solar, está íntimamente ligado con el trabajo de investigación de los expertos en iluminación natural. Muchos de sus trabajos evalúan la apetencia de los usuarios por la presencia de la luz solar en los interiores. Los matices de Granger aparecen repetidamente mencionados en los trabajos de investigación, preocupados tanto por los efectos térmicos como por los lumínicos. Incluso, Granger apunta a una de las cuestiones que Wang pretende esclarecer respecto a la adecuada presencia de un área soleada en relación a la posición que ocupa un usuario (Wang & Boubekri, 2010, 2011). Los comentarios de Granger continúan con la cita de las palabras de Bailly, que exponen los efectos positivos de la luz solar sobre el individuo, tanto los fisiológicos como los psicológicos. Más adelante, la tesis recupera la aportación de las investigaciones en las que, a través de encuestas, los usuarios se han pronunciado sobre los efectos vivificantes de la presencia de la luz solar en los interiores. Como se verá, los estudios no sólo

[7] Pierre Bailly era un médico originario de la Champagne que publicó en 1628 una obra de vulgarización médica titulada: *Questions naturelles et curieuses, contenans diverses opinions problématiques recueillies de la médicine, touchant le régime de la santé, où se voient plusieurs proverbes populaires, fort plaisants et récréatifs qui se proposent journellement en compagnie, curieusement recherchées et résolues*.

abordan las preferencias de los usuarios sino que las cotejan con la eficiencia visual y mental de los usuarios.

En segundo lugar, Granger apunta las posibles reacciones que provoca una excesiva radiación solar sobre el cuerpo humano citando, con cierta ironía, las advertencias alarmantes que en 1684 escribió el médico francés Antoine Porchon[8] en sus famosas *Règles de la Santé*:

> Seulement voilà, trop excessive ou trop prolongée, la chaleur du soleil, qui altère les propriétés de l'air et en raréfie la présence, est aussi tenue pour périlleuse. Elle « enflamme les esprits, échauffe les humeurs, les dissout et les subtilise, augmente la bile, exténue les corps, ouvre les pores, provoque la sueur, abat les forces, affaiblit la coction et ôte la vie en dissipant la chaleur naturelle. »

La contribución del segundo apartado de este capítulo no hace hincapié en los efectos nocivos que provoca una excesiva exposición a la radiación solar. Al contrario, pone en valor los efectos positivos, tanto los fisiológicos como los psicológicos, que una presencia solar correcta, regulada por el buen diseño de un interior, puede provocar sobre un usuario. Consciente o inconscientemente, éstos son los efectos que desean los usuarios cuando se pronuncian a favor de la presencia solar en los espacios.

2.3.1. Usos y requerimientos de luz solar

En 1945, el *British Standard Code of Practice on Sunlighting for houses, flats and schools* (B.S.I., 1945) explicitó datos sobre la cantidad de luz solar deseable en los edificios a través de unas encuestas realizadas en 1944. Las entrevistas fueron realizadas durante los años de guerra, pudiéndose ver afectadas por las difíciles condiciones del día a día. Treinta años más tarde, con motivo de la revisión del *British Code of Practice*, el proyecto de investigación titulado *Sunlight in Buildings* propuso

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[8] Porchon, A. (1684). *Les règles de la santé, ou le véritable régime de vivre, que l'on doit observer dans la santé et dans la maladie*. Paris: Villery, p. 3.

actualizar el trabajo de 1945, teniendo en cuenta los cambios que después del tiempo transcurrido habían afectado a la edificación, la actitud y los estándares ambientales. El proyecto duró tres años, fue dirigido por Eligahy Ne'eman, llevado a cabo por un equipo de la asesoría ambiental de Ralph Hopkinson y Newton Watson y el informe final fue entregado al Steering Committee of the Department of Environment, la institución que lo financió (Hopkinson & Watson, 1973/74). En relación a la presencia solar, los directores del proyecto consideraron que, hasta la ocasión, los aspectos térmicos habían sido más desarrollados que los lumínicos. Por tanto, la ocasión era la adecuada para hacer énfasis en los lumínicos. Fruto del proyecto, diversos documentos científicos fueron publicados. Muchos de sus resultados son una clara referencia para esta tesis que, como se verá más adelante, pretende dar continuidad a algunos aspectos. El primer artículo, publicado en 1976 bajo el título *Sunlight Requirements in Buildings – I. Social Survey* (Ne'eman, 1976) reúne los resultados de las encuestas realizadas a 647 entrevistados que ocupaban cuatro tipos de edificios (viviendas, colegios, oficinas y hospitales) ubicados en Londres. Aunque el estudio publica los resultados vinculados a los cuatro tipos de edificios por separado, las conclusiones generalizan y pueden resumirse en dos propuestas:

En primer lugar, el trabajo presenta unas afirmaciones respecto a lo receptivos que son los usuarios en relación a la presencia solar en los espacios. A continuación, dichas afirmaciones aparecen recapituladas:

- El acceso de la radiación solar aporta bienestar pero no es identificado como prioritario si el resto de componentes ambientales provocan satisfacción.

- Su presencia se identifica como crítica en relación a dos situaciones: primero, cuando remedia deficiencias (térmicas o lumínicas); segundo, cuando su exceso puede causar molestia.

- Debe proporcionarse el acceso solar controlado ya que mejora la experiencia visual y térmica.

- El acceso controlado requiere tener en consideración las actividades y las posiciones de trabajo para evitar las posibles molestias térmicas y visuales. En las situaciones más difíciles un control flexible facilitará el propósito.

- La flexibilidad funcional requiere contemplar su contrario, la inflexibilidad debida a equipamientos o posiciones de trabajo fijas. En consecuencia, el usuario es menos flexible y, por tanto, más susceptible a poner en crisis el acceso solar por motivos visuales (deslumbramiento) o térmicos.

En segundo lugar, el trabajo propone tratar los requerimientos en relación con el tipo de tareas que ocurren en los edificios. Dichas tareas a menudo se repiten en edificios con diferentes usos. Consecuentemente, el trabajo publica el primer borrador de una tabla que relaciona los requerimientos que regirían la presencia de luz solar en relación a una clasificación de tareas.

El trabajo extiende las conclusiones a un usuario genérico, sin discutir sobre el lugar de residencia de los sujetos. Sin embargo, el mismo autor publicó dos años antes, un artículo bajo el título *Visual Aspects of Sunlight in Buildings* (Ne’eman, 1974), en el que anticipaba una selección de los resultados y reflexionaba sobre la posible repercusión de la procedencia de los resultados. En ausencia de resultados correspondientes a otros lugares del planeta, Ne’eman proponía una hipótesis: “en las regiones cálidas el sol brilla en abundancia y los habitantes toman precauciones para evitar la exposición al sol. En cambio, los habitantes de climas más fríos, particularmente los de las regiones pobladas del hemisferio norte, parecen desarrollar un insatisfecho deseo por la luz solar. Ellos se sienten atraídos por los beneficios de la luz solar y su simbólica influencia está ampliamente explotada en la publicidad y en los incentivos comerciales.” Pese a la hipótesis, el autor deja entrever que estudios similares a los del trabajo *Sunlight in Buildings* serían convenientes y darían lugar a la concreción en una comparativa. En esta tesis, el capítulo vinculado a los casos de estudio presenta los resultados de las encuestas a un reducido número de usuarios en las que se les interroga sobre su sensibilidad frente al deslumbramiento causado por la presencia solar. Los entrevistados dejan constancia de su nacionalidad y comunican al entrevistador las condiciones lumínicas habituales (predominio de la luz natural o artificial) en sus puestos de trabajo. El comentario de los resultados discute la posible repercusión de la educación cultural debida a la nacionalidad o los posibles prejuicios consolidados por sus costumbres.

Volviendo a los resultados de *Sunlight Requirements in Buildings – I. Social Survey*, los autores no proponen conclusiones específicas para para cada uno de los 4 usos. Para identificarlas, la lectura del comentario de los resultados es obligada. Dada la relevancia de este estudio, este subcapítulo propone una síntesis de los aspectos más relevantes y los complementa con reflexiones vinculadas al contenido de la tesis.

En el caso de las viviendas, los autores citan repetidamente el trabajo de Bitter & van Ierland (1965). Este antecedente les sirve a los autores para el planteamiento de su cuestionario y para tener claramente identificadas las cuestiones más relevantes del acceso solar en las viviendas.

Mayoritariamente, los usuarios se encuentran satisfechos con el acceso solar en sus viviendas. Los ocupantes proceden de viviendas en peores condiciones ubicadas en el mismo barrio humilde y su traslado a estas viviendas es relativamente reciente. En la mayoría de los casos, residen allí desde hace un año. Aparentemente, los tres grupos de viviendas sociales reúnen unas buenas condiciones. Específicamente, muy pocas salas de estar están mal orientadas (entorno a una orientación norte). Cuando se les interroga sobre los motivos de su satisfacción frente al acceso solar, los usuarios expresan que es algo natural, sin poder etiquetarlo. Cuando se les propone unos motivos, aquel que más frecuentemente se señala está vinculado con los beneficios terapéuticos. En segundo lugar, ellos identifican que la luz solar mejora la apariencia de los interiores y seguidamente identifican que proporciona calor y, en último lugar, otorgan el protagonismo a la luz. Algo particular de este estudio es que enfrentan dos posibles elecciones relacionadas con las presencia de la luz solar. La primera da a elegir entre la presencia solar en el interior o el exterior. El número de encuestados que la prefiere en el interior duplica a los que la prefiere en el exterior. Sin duda, la ubicación de los tres grupos de edificios en Londres explica el deseo del acceso solar en el interior. Prueba de ello es un comentario frecuente cuando se les interroga sobre la posibilidad de modestia visual (deslumbramiento) o térmica (sobrecalentamiento): “we see the sun so seldom in this country that we mustn’t complain about it”. La segunda elección plantea el dilema que sería escoger entre una buena vista hacia el exterior y el acceso de la radiación. Mayoritariamente escogen la vista y muchos lo defienden con un argumento bastante rotundo: “you can look to a nice view all the year”. El contexto vuelve a ser decisivo. Los usuarios son sabedores de que, en Londres, una buena orientación (la de sus viviendas) no garantiza la presencia solar, escasa a causa de la alta probabilidad de nubosidad. Siendo la vista un elemento relevante, el cuestionario les interroga sobre el tipo de vista que prefieren. La respuesta es unánime y apunta a los paisajes naturales. Su condición urbana no olvida el placer ambiental que procura el medio natural.

Si en el caso anterior el trabajo de Bitter & van Ierland (1965) puede entenderse como un punto de partida, **en el caso de los colegios** el trabajo parte de una encuesta previa a la que responden 24 escuelas en diferentes puntos del país. Sirve para identificar las molestias en relación a los problemas de uso de una escuela y, entre ellos, los ambientales. De entre los problemas sugeridos, los profesores destacan seis que pueden ordenarse según su puntuación del 1 (pequeño problema) al 10 (gran problema). Guardando relación con el acceso solar, el sobrecalentamiento ocupa la 4ª posición (5.7) y el deslumbramiento la 6ª (4.2).

Realizado este primer sondeo, el trabajo procede con las encuestas detalladas que, sin que sean idénticas, repiten las cuestiones fundamentales planteadas en el caso de las viviendas. Una particularidad de la encuesta es que los entrevistados son los profesores y no los alumnos. Pese a ello, todos ellos responden teniendo en cuenta los problemas ambientales en el aula y, por tanto, el confort de los alumnos. Considerando la exigencia de la tarea visual y la inflexible posición de los alumnos, el grado de confort es más exigente y genera una proporción mayor de respuestas que juzgan con reserva la presencia del acceso solar en las aulas (47% identifica que causa molestias térmicas o visuales; 52% que es causa de molestia sin detallar más). En relación a ello, muchos identifican que el acceso solar es suficiente en sus aulas (43%), prefieren visualizar la presencia solar en el exterior (53%) y muy pocos privilegiarían el acceso solar frente a unas buenas vistas (18%), asociadas a un vista “natural” (67%). Pese al riesgo de molestia, un 46% afirma que les gusta la presencia solar en el interior y un 50% que les disgusta. Entre los disgustados (59), 31 señalan las molestias visuales. Pese a que se citan las quejas de los alumnos, estos últimos resultados no son del todo excluyentes en cuanto a la presencia de luz solar. Los entrevistados identifican sus efectos psicológicos positivos (positivismo y eficiencia) tanto para el profesor como para los alumnos. Además, los profesores subrayan que la molestia está vinculada al contacto físico con la radiación y, consecuentemente, dan pie a la presencia solar en el interior si está al alcance de la vista sin llegar a los pupitres.

En este caso de las oficinas, el cuestionario utilizado es similar al anterior. Aunque el texto ofrece datos limitados sobre las oficinas, su situación frente a la luz natural es equiparable y permite que la suma de los resultados dé lugar a una valoración porcentual global. Desde el principio, el trabajo subraya lo conflictiva que puede ser la postura de los sujetos frente al acceso solar. Por una parte, los efectos de la luz solar son deseados (75%) pero su presencia en el interior es más conflictiva en función de si entorpece las tareas. Dicha presencia es un placer para el 34% de los encuestados; su postura es opuesta a la del 38% que juzga que la misma presencia solar genera molestia térmica o lumínica. Esta división se extiende al juicio que hacen de la presencia cuantitativa de la luz solar en sus oficinas ya que un 47% la juzga suficiente. Aparentemente, los que advierten el riesgo de molestia lo hacen por sugestión ya que solo un 15% identifica la penetración de la luz solar como excesiva. Siguiendo con las ambivalencias, un 52% afirma desear la presencia de la luz solar en el interior e incluso un porcentaje bastante elevado (35%) la preferiría frente a la vista. Aún y así, sigue siendo predominante el porcentaje (62%) que prioriza las vistas a la penetración solar. Respecto al contenido de la vista, la vista preferida seguiría siendo la natural aunque en este caso su porcentaje no destaca tanto (36%). Muy posiblemente, la visión del contexto urbano promueve la actividad y es reconocida como acorde con una actitud laboral activa. Apoyando esta hipótesis, propia del que escribe, los autores del texto especifican que los ocupantes del edificio M, ubicado en un área rural, afirmaban que les gustaría tener unas vistas que contuvieran cierta actividad. El texto propone que dos aspectos podrían justificar las ambivalentes respuestas de los usuarios. Primero, el texto afirma que pese a que las posiciones de trabajo son fijas en una oficina, los usuarios consideran que debe ser posible que el espacio admita cierto acceso solar sin afectarles hasta el punto de tenerse que mover. Consideran así que su espacio es más amable ya que las manchas solares sugieren el contacto con el exterior, algo que aprecian y que convierte su puesto de trabajo en un lugar más atractivo. Esto último es lo que defiende esta tesis demostrando además que la presencia solar no causa deslumbramiento por definición. Segundo, el texto señala que, si existen medios para garantizar un buen control solar, la satisfacción de los usuarios les lleva a negar los posibles efectos dañinos de la radiación solar. El texto identifica que, en los casos de estudio, este control no estaba bien garantizado y motivaba una alta susceptibilidad de los usuarios ante la molestia posible. Teniendo en cuenta esto, los autores afirman que son necesarios más esfuerzos para optimizar los sistemas de control sin que excluyan totalmente la penetración solar.

Las encuestas en los hospitales no están faltas de interés. Según se indica, en 1976, el año de publicación del artículo, existían pocos estudios realizados en estos edificios. Una lectura crítica sugiere hasta cinco motivos por los que la lectura de los resultados y la extracción de conclusiones son menos fiables en comparación con las de los usos. Primero, el número de encuestas es mucho menor que en los casos anteriores. Esto es debido a la menor disponibilidad de los pacientes y del personal. El segundo motivo está vinculado a las características de los hospitales. Dos de ellos son del primer tercio de los años 30 y están ubicados en zonas urbanas de considerable densidad. La penetración solar en los interiores está bastante coartada. Las condiciones del tercer hospital son muy diferentes. Construido en los años 60, el edificio cumple con las consideraciones higienistas y está ubicado en un entorno suburbano calificado como excelente, que posibilita buenas vistas a zonas verdes. El tercer motivo guarda relación con la estación del año en que se realizaron las encuestas. Las tres entrevistas en los tres hospitales fueron realizadas en tres estaciones diferentes (verano, invierno y otoño) pudiendo afectar el deseo de luz solar en los interiores en función de las condiciones climáticas. El cuarto motivo, y más delicado, es que las encuestas evalúan la opinión de los pacientes y del personal. La situación de ambos colectivos es muy diferente. El personal viste prendas comunes, tiene una ocupación activa que implica movimientos (fundamentalmente el personal sanitario, no tanto el administrativo) y la exigencia visual de sus tareas suele ser alta. En cambio, los pacientes, yacen en camas o en asientos para el reposo. Aunque muchas veces pueden variar su acomodación, están convalecientes, con poco movimiento y ropa; es de suponer que serán menos calurosos y menos exigentes desde el punto de vista visual y, por tanto, más permisivos frente a la penetración solar. El comentario de los resultados exige a menudo diferenciar entre los pacientes y el personal de hospital, cuestión que hace menos factible una recomendación única.

Un quinto motivo que podría condicionar las respuestas es que la convalecencia de todos los pacientes es diferente y este hecho puede influir claramente en su deseo de contacto con el exterior. A diferencia de ellos, el personal ocupa el hospital regularmente y utiliza espacios sometidos a condiciones ambientales muy diferentes (principalmente, secretaría, enfermería y laboratorio). Otro agravante es que las respuestas del personal no aparecen desglosadas por hospitales y esta cuestión es crítica ya que las condiciones de uno de los tres hospitales son notablemente diferentes.

Siendo conscientes de todas estas limitaciones, los dos colectivos aceptan la penetración solar. Los pacientes son incondicionales y están muy predispuestos a su presencia (el 76% considera que es un placer). En cambio, el personal es algo reticente debido a las molestias térmicas y lumínicas que conlleva (el 14% considera que es un placer pero también una molestia y solo el 24% destaca la molestia que causa). Ante la pregunta directa que obliga a asociar la luz solar con el placer o la molestia, los pacientes se decantan por el placer (91%) y el personal por la molestia (62%). Cuando se les propone mencionar las razones que motivan su gusto o disgusto en relación a la presencia solar en los hospitales, tanto los pacientes como el personal lo vinculan a los beneficios terapéuticos (41 y 40%). Igualmente, ambos colectivos consideran que la presencia solar mejora la apariencia del interior (23%). Por lo visto, el placer estético y el beneficio terapéutico están vinculados. El personal penaliza las molestias que la luz solar puede ocasionar: el 14% habla de disgusto por motivos térmicos y el 17% asocia dicho disgusto con cuestiones lumínicas. En cambio, como era previsible, la luz (14%) y el calor (8%) son considerados beneficios por los pacientes. Extrañamente, cuando se les pregunta acerca de la cantidad de luz en los interiores, el 47% de los pacientes no responde, al igual que el 69% del personal. Entre los que responden, el 44% de los pacientes considera que la penetración solar es suficiente y el 28% del personal considera que es insuficiente, poniendo de manifiesto las diferentes posturas de ambos colectivos. Curiosamente, cuando se les interroga sobre su preferencia en relación a la presencia solar, en el interior o en el exterior, tampoco son muchos los que se manifiestan: un 49% de los pacientes no aporta información y un 86% de los empleados tampoco. Los pocos que se pronuncian se decantan por su presencia en el exterior. Y, si tienen que escoger entre vistas o penetración solar, ambos colectivos prefieren las vistas de igual manera (56% de los pacientes y 55% de los empleados). Pese a ello, cabe decir que los porcentajes que privilegian la penetración solar no son despreciables: el 35% de los pacientes y el 31% de los empleados. En cuanto al tipo de vistas que prefieren, los empleados privilegian el contenido natural (52%). En cambio, los pacientes están más interesados por unas vistas que impliquen actividad y distracción (38%). Así, los que prefieren las vistas naturales son menos (23%).

2.3.2. Luz solar y efectos saludables

Numerosos estudios demuestran los efectos positivos sobre el bienestar general y la psicología de los usuarios debidos a la presencia de la luz natural en el interior de los edificios. Su contribución en el buen desarrollo de las tareas es clara. Los estudios demuestran que la luz natural provoca mejoras en la productividad en las escuelas y en las oficinas (Charles & Veitch, 2002; Edwards & Torcellini, 2002; Ne'eman, 1984), unas mayores ventas en los edificios comerciales (Heschong Mahone Group, 1999; Romm & Browning, 1994), la reducción del tiempo de hospitalización de los pacientes de los hospitales (Baeuchemin & Hays, 1996; Benedetti, Colombo, Barbini, Campori, & Smeraldi, 2001; Ulrich, 1984; Verderber, 1983), el aumento de la satisfacción y del bienestar en el trabajo (Butler & Biner, 1987; Collins, 1975; Heerwagen & Orians, 1986; Leather, Pyrgas, Beale, & Lawrence, 1998; Yildirima, Akalin-Baskayab, & Celebia, 2007).

¿Pero a qué se debe la abundancia de reacciones positivas? ¿Es tan sólo cuestión de la materia simbólica de la luz que, tras años de presencia en los edificios más representativos de las civilizaciones, ha inculcado a los espíritus mensajes celestiales? Cautivo del simbolismo de la luz solar, Procopius, tras visitar en el siglo VI la iglesia bizantina de Santa Sofía (Estambul), dijo: “(tan) singularmente llena de luz, y de luz solar, (que) no parece iluminarse a través del sol del exterior, sino a partir de la luz celestial del interior”. Y sigue con la descripción de la cúpula apoyada sobre un tambor perforado con ventanas a través del que se manifiestan los rayos solares: “no parece descansar sobre una base sólida sino cubrir el lugar de abajo como si estuviera suspendida por la cadena de oro mitológica”. Más allá del simbolismo, y sin dejar lugar a la interpretación, los argumentos fácticos de la investigación médica ponen de manifiesto las reacciones fisiológicas que provoca la luz solar en el ser humano y sus frecuentes implicaciones psicológicas. El propósito de este subcapítulo es recopilar las reacciones más relevantes, apoyándose en la subdivisión que propuso Boubekri cuando publicó el artículo ‘An Argument for Daylighting Legislation Because of Health’ (Boubekri, 2004a).

Luz y síntesis de vitamina D:

La vitamina D ayuda a que el cuerpo humano regule la absorción y el uso del calcio y del fósforo, vitales para el crecimiento y el endurecimiento de los huesos y los dientes. La vitamina D estimula la absorción y reabsorción en los riñones y ayuda a mantener los deseados niveles de calcio y fósforo en la sangre. Cuando la piel se expone a la radiación UV-B (longitud de onda 290-315 nm), convierte en vitamina D una pro-hormona encontrada en la piel. Esta viaja hasta el hígado donde queda almacenada bajo la forma 25-dehydroxyvitamina D (25-OHD), presente en el suero sanguíneo y que se detecta en las analíticas (Glerup, 2000). Pues bien, los estudios estiman que, en condiciones normales, la piel podría producir entre 80-100% de la tasa requerida por día (Glerup, 2000). Su insuficiencia puede ser complementada con la ingesta de alimentos. Pese a ello, los estudios demuestran que la mayoría de los adultos sanos que viven en los Estados Unidos presentan deficiencia de vitamina D (Fuller, 2003). Otros estudios demuestran que, a pesar de los complementos vitamínicos, los niveles de vitamina D serán bajos si la exposición a la radiación es insuficiente. Finalmente, cabe mencionar que la deficiencia vitamina D puede ser relacionada con otras enfermedades graves como serían cambios en la presión arterial y la Osteodistrofia renal, vinculada a un fallo renal crónico. Prasad *et al*. (2001) han demostrado que, cuantas más horas de exposición a la radiación solar, más normalizada deviene la presión arterial.

Luz y sistema endocrino humano:

El hipotálamo es un área de nuestro cerebro responsable de numerosas funciones vitales para nuestro organismo. La glándula pineal del hipotálamo, un componente del sistema endocrino humano, gestiona la producción de hormonas que orquestan los procesos químicos y físicos del metabolismo. Esta glándula reacciona diariamente, al compás del biorritmo humano, ante la luz natural que sirve como catalizadora de la secreción de dos poderosas hormonas, la serotonina y la melatonina. Ambas determinan los niveles de energía y actividad de nuestro cuerpo. Ante bajos niveles de luz, aumenta la producción de la melatonina, responsable de los síntomas de sopor y somnolencia. La luz natural suprime la producción de melatonina y despierta la mente con la producción de serotonina. El núcleo supraquiasmático es el regulador hormonal que acompasa el reloj interno o circadiano. El SAD (Seasonal Affective Disorder) es una depresión diagnosticada en los habitantes de las latitudes de más al norte. Se estima que más de un millón de americanos sufren esta depresión. Las investigaciones científicas han comprobado que existe la correlación entre la vulnerabilidad de las personas y la exposición a la luz solar, estando ampliamente aceptado que pocas horas de luz natural serían las causantes de altos niveles de melatonina. Nayyar *et al*. (1996) demuestran que, para los afectados por el SAD, la depresión empeora en cualquier momento del año cuando el cielo está cubierto y/o la luz en los interiores decrece. Lam *et al*. (2001) anotan que la depresión invernal de estos pacientes aumenta cuanto más al norte viven. Rosenthal (1984) propuso terapias que alargaban las horas de exposición a la luz del usuario durante el invierno mediante su exposición a la luz artificial de 6 a 9 de la mañana y de 4 a 7 de la tarde. Los efectos positivos sólo eran apreciables cuando el nivel lumínico era alto (2500 lux), del orden de 5 veces mayor que las condiciones normales de iluminación artificial. Otros estudios añaden que la duración de la exposición y la calidad espectral de la luz juegan también un papel importante sobre los efectos positivos de la terapia (Wirz-Justice, 1998; Graw *et al.*, 1998).

Calidad espectral de la luz:

La investigación de Neer (1977) centra la atención en la calidad espectral de la luz solar. Su experimento utiliza una fuente de luz artificial que imita el espectro de la luz solar y sus resultados demuestran aumentos en la absorción intestinal de calcio, saludable para el organismo, en sujetos mantenidos en un interior durante el invierno. De nuevo, los niveles lumínicos exigidos son elevados (5000 lux), alejados de las situaciones reales. Otros estudios (Veitch & McColl, 2001) intentan demostrar la importancia de la calidad espectral utilizando fluorescentes de espectro total. Su voluntad es relacionar este tipo de luz con los efectos positivos en el humor aunque sus resultados no logran ser tan concluyentes como se quisiera. Sin duda, demostrar la contribución de la calidad espectral añade un grado de dificultad. En el campo de la investigación biomédica, los investigadores de la United States Environmental Protection Agency (EPA) centran la atención en la radiación ultravioleta contenida en el espectro. Su trabajo analiza si distintas fuentes de luz (solar, fluorescente y luz de cama solar), con distintas proporciones en los distintos tipos de radiación ultravioleta (UVA, UVB y UBC), provocan distintos efectos mutagénicos en las bacterias utilizadas comúnmente para los experimentos de laboratorio, aunque el mismo experimento podría realizarse con células mamíferas (De Marini *et al.*, 1995). Los resultados demuestran que los efectos mutagénicos dependen tanto de la cantidad total de radiación ultravioleta contenida en el espectro, como de la cantidad relativa de UVB en relación a UVA. Todos estos resultados, aunque no siempre concluyentes, indican que es la naturaleza del espectro de la luz solar la que provoca una mejoría única en la salud. Muchas de las fuentes de iluminación artificial no replican el espectro solar. Además, la composición espectral de la luz solar cambia de acuerdo con la hora del día y las estaciones (Diffey, 2002). Este ciclo cambiante puede ser la razón principal de los ritmos circadianos, asumiendo que las reacciones químicas para promover estos biorritmos se inician sólo más allá del umbral de la radiación ultravioleta.

Considerando todo lo comentado anteriormente, uno podría acabar diciendo que la salud no está en riesgo si los usuarios pasan las suficientes horas en el exterior de los edificios. Incluso, uno podría aventurarse a afirmar que, por lo menos en las regiones con largas horas de luz solar, no debería existir un riesgo de falta de exposición a la radiación solar. Pues bien, la realidad no valida la hipótesis. Un estudio examina el grado de exposición a la luz natural en la población adulta (entre 40 y 64 años) de San Diego, California, y demuestra que la población pasa poco tiempo en el exterior. Dicho estudio expande los resultados de otras investigaciones anteriores que confirman que los individuos no se exponen lo suficiente a la luz del día (Campbell *et al.*, 1988; Kripke *et al.*, 1989; Okudaira *et al.*, 1983; Savides *et al.*, 1986). Ante tales demostraciones, la presencia de la luz solar en los interiores debería ser un imperativo que el diseño y la regulación normativa deberían aceptar y garantizar. El siguiente capítulo aborda la cuestión.

2.4. Diseñar la presencia de la luz solar

El diseño arquitectónico no una es tarea fácil ya que pone a prueba la habilidad del proyectista para resolver simultáneamente múltiples objetivos, de condiciones muy diversas. Lam (1986) propuso cinco categorías para sintetizar la amalgama de objetivos:

1. Proveer al usuario de confort y placer gracias al ambiente interior
2. Satisfacer las necesidades programáticas de los usuarios
3. Minimizar el coste energético del edificio
4. Optimizar la imagen pública de la arquitectura
5. Minimizar el coste inicial de construcción

El proyectista resuelve el rompecabezas del diseño cuando optimiza las soluciones y pone en práctica recursos que sirven para dar respuesta, simultáneamente, a las cinco categorías mencionadas. La presencia de la luz solar en los interiores es uno de ellos ya que garantiza el confort de los usuarios proporcionándoles la convivencia con el entorno soleado que tanto valoran y que, como se ha visto en el capítulo anterior, su salud tanto agradece. Simultáneamente, dicho diseño repercute positivamente sobre el consumo energético. Su contribución notable en el acondicionamiento térmico y lumínico reduce el costoso consumo eléctrico y, no sólo eso, también disminuye la demanda y los costes de partida vinculados. A la reducción de los gastos podría añadírsele también el aumento de los beneficios si se piensa en un edificio en el que se desarrolla una actividad laboral. Las condiciones de trabajo puede mejorar con la presencia solar y con ellas la productividad de los empleados cuyos salarios representan, a menudo, el mayor coste de la actividad en el edificio, relegando en segundo lugar los gastos de alquileres y consumos de suministros.

Los comentarios del párrafo anterior trasladan la discusión al territorio de los interiores arquitectónicos. Los usuarios de los espacios experimentan sensaciones de confort y placer cuando conviven con un espacio bien diseñado. El capítulo 2.2 hace referencia al reto que supone para un fotógrafo profesional convertir la experiencia de un espacio en imagen. Fotógrafos de prestigio toman la palabra y sugieren que la experiencia del lugar es inigualable. Aquel que pretenda extraer un juicio inequívoco en relación al diseño de un espacio deberá visitarlo obligatoriamente. Los prestigiosos premios Aga Khan de arquitectura islámica no ignoran este requisito. Los miembros técnicos de su jurado visitan los edificios y experimentan en primera persona las sensaciones que transmiten los interiores. Además de no dejarse llevar por la representación sesgada que una imagen ofrece de la realidad, el procedimiento garantiza la relevancia del diseño ambiental de los interiores. Sin embargo, el público general (aquellos que no viven los edificios) y la prensa arquitectónica parecen reconocer sobre todo las virtudes del exterior de los edificios. Aunque el exterior es indudablemente importante, los problemas ocurren cuando los arquitectos se dejan llevar por esta preocupación. Un concepto de edificación confortable y agradable, bellamente vestido, será duradero; pero un edificio basado en un concepto bello de piel es improbable que sea placentero para sus ocupantes o que conserve su singularidad externa a través del tiempo.

A continuación, este subcapítulo describe los aspectos relevantes que deben tenerse en cuenta para resolver con éxito el encuentro entre la presencia de la luz solar y la satisfacción visual experimentada por el usuario ante tal presencia. El contraste lumínico es el denominador común de muchos de los aspectos que aparecen destacados.

- La presencia de la luz solar puede ser bienvenida si no incide en las superficies sobre las cuales los usuarios desarrollan tareas visuales.

- Los reflejos solares pueden ser tolerados sobre superficies que no sean las de trabajo a pesar de los contrastes lumínicos que provocan. La percepción logarítmica que caracteriza los sentidos humanos permite la adaptación ante condiciones visuales diversas. Un usuario puede ver tanto en el fondo más oscuro de una sala como en la zona próxima a la ventana o a un parche de sol. Si los diseños pretenden minimizar las zonas oscuras no es tanto por la falta de visibilidad sino porque son poco alegres.

- Un diseño lumínico ambicioso convierte la existencia de contraste en virtud. Un contraste lumínico descontrolado ocasiona deslumbramientos pero, diseñado y controlado, da lugar a reflejos interesantes.

- Así, la definición de un ambiente visual rico sería la de aquel que satisface la necesidad de interés visual de los ocupantes. Un buen diseño de la presencia solar contribuye favorablemente, destaca las superficies de interés mientras que las que carecen de interés pasan desapercibidas.

- Al contrario, un ambiente luminoso pobre sería aquel que no se vale de los contrastes para cualificar positivamente el espacio. Su iluminación es uniforme y carente de interés visual.

En definitiva, el diseño de la presencia solar ofrece la oportunidad de apostar por soluciones lumínicas cualitativas en sintonía con las características geométricas de los interiores. Esta alternativa de diseño propone conceptos ambientales, crea entornos visuales que la percepción de los usuarios sabe apreciar y niega las soluciones estrictamente cualitativas basadas en conseguir unos niveles lumínicos que, seguramente, ni el ojo experto de un diseñador lumínico sabría distinguir. Dicho de otro modo, el diseño de la presencia solar no debe pensarse atendiendo sólo a la distribución lumínica puntual. El diseño debe incluir la preocupación por el contraste visible entre los diferentes puntos del espacio, por el balance lumínico que sí perciben los usuarios que experimentan un espacio. Tal diseño descarta la uniformidad como valor y apuesta por la variedad, una cualidad que los usuarios y arquitectos aprecian. Phillips (1975) afirma que no es necesario convencer a los arquitectos al respecto de las virtudes que la variedad del ambiente visual aporta. Phillips añade que siente una simpatía inmediata con la crítica de la arquitectura moderna que hace Gropius cuando dice: “the sun goes round and nothing happens”.

En los subcapítulos que siguen, un recorrido por la historia de la arquitectura reconoce la existencia de las obras y las normas que ejemplifican el interés por diseñar convenientemente la presencia solar en los interiores (subcapítulo 2.4.1). Tras dicho recorrido, la propuesta es centrarse en la normativa actual (2.4.2), para describir sus virtudes y carencias. A continuación, el interés recae en las tentativas de los investigadores por suplantar las carencias con nuevos criterios (2.4.3). Finalmente, una breve explicación justifica la contribución de la tesis (2.4.4).

2.4.1. Recorrido histórico: obras y normas

En 2008, Boubekri publica el libro *Daylighting, Architecture and Health*. Su primer capítulo "*Designing with the sun: a historical perspective*" traza un interesante recorrido por la historia en el que identifica las arquitecturas (vernáculas y algunas de estilo) proyectadas con una evidente vocación por garantizar el acceso de la luz solar. Aunque muchos ejemplos destacan más bien la vocación térmica e higiénica de dicha presencia, la contribución lumínica está implícita en muchos comentarios. Su contribución no plantea una división estricta entre los efectos de la luz directa del sol y la luz difusa del cielo. No obstante, el lector puede identificar claramente cuando Boubekri incluye ambos conceptos o cuando uno de los dos es el que motiva su reflexión. Uno de los aspectos más relevantes del trabajo de Boubekri es que da testimonio de las recomendaciones y normas que, a modo documento técnico, han servido para pautar el diseño de la presencia solar. A continuación, este subcapítulo destaca las aportaciones que mejor ilustran la complicidad entre arquitectura y luz solar.

La Antigüedad da lugar a los primeros ejemplos. En el Antiguo Egipto el supremo gobernante es el "Gran Dios Ra", demiurgo, dios del cielo, del sol y del origen de la vida en la mitología egipcia. Su iconografía es la de un hombre con cabeza de halcón sobre la cual luce un disco solar. Las creencias religiosas dieron lugar a la construcción de ciudades y de templos dedicados al sol y su presencia. La ciudad faraónica de *Iunu*, a la que los griegos nombran Heliopolis o la 'ciudad del sol', representó el centro geográfico del culto al sol que existió en Antiguo Egipto. Desafortunadamente, poco se sabe hoy de aquella ciudad. Otro ejemplo más conocido es el templo de Karnak, conocido como el templo del solsticio solar ya el diseño del templo respetaba alineaciones que correspondían con los solsticios de verano y de invierno. Alejados en el planeta, los Incas también celebraban el solsticio de verano con solemnidad y reverencia y, a lo largo del año, hacían uso de su poder para calentarse. Los Incas construyeron la ciudad de Machu Picchu a 2430m sobre el nivel del mar, orientando la edificación hacia el sol para capturar y almacenar calor. Dada la altitud, la provisión de madera combustible era costosa y, por tanto, debieron aportar la calefacción solar pasiva. La ciudad alojaba también un templo dedicado al dios sol, el Templo del Sol, conocido también como Intihuatana.

Diseminados por el planeta, otros pobladores consideraron la contribución de la energía solar para acondicionar sus hogares. La arquitectura popular dio lugar a formas basadas en las cuevas primigenias, escavadas en rocas o construidas bajo tierra. Los ejemplos de estas construcciones abundan en diferentes rincones del planeta: la ciudad troglodítica de Matmata (Túnez), las viviendas enterradas en Xian (China), la Cappadocia (Turquía), Guadix (España), los graneros en los riscos de Teli en el territorio de Dogon (Mali), las viviendas encaladas en las rocas de Santorini (Grecia), los templos budistas en las cuevas en Datong, Shanxi (China), las viviendas en Mesa Verde (Colorado), la White House en Canyon de Chelley (Nuevo México)...

La Grecia clásica también consideró la presencia solar en su diseño urbano y en la formalización de su arquitectura, tanto en la sagrada como en la doméstica. Sus diseños estaban claramente orientados en función del sol, ya fuese para rendirle reverencia o para aprovechar su energía y acondicionar los hogares. La justificación la encontramos en los restos arqueológicos y en los textos de los teóricos del período. En el 400 a.C., Sócrates escribió los principios básicos del diseño basado en el aprovechamiento de la energía solar. Strauss (1972) tradujo al inglés lo que Jenofonte, el renombrado filósofo e historiador griego, transcribió en su libro titulado *Recuerdos de Sócrates*:

> Now in houses with a south aspect, the sun's rays penetrate into the porticos in winter, but in the summer, the path of the sun is right over our heads and above the roof, so that there is shade. If then his is the best arrangement, we should build the south side loftier to get the winder sun and the north side lower to keep out the winter winds. To put it shortly, the house in which then owner can find a pleasant retreat at all seasons and can store his belongings safely is presumably at once the pleasantest and the most beautiful.

El dramaturgo Esquilo creía que sólo los 'bárbaros' y los 'primitivos' vivían en cuevas y en lugares desprovistos de luz solar. (Butti & Perlin, 1980) tradujeron al inglés lo que Esquilo observó en *Prometeo Encadenado*:

> Though they had eyes to see, they saw to no avail; they had ear, but understood not... They lacked knowledge of houses turned to face the winter sun, dwelling beneath the ground like swarming ants in sunless caves.

Además de identificar que el sol era fuente de calor, los griegos identificaron que fomentaba la buena salud y, por tanto, que la fachada sur debía ser considerada como la más saludable. Oribasio de Pérgamo, un eminente escritor griego en medicina, escribió en el siglo IV a. C. que el norte era el lado menos saludable de un edificio. (Grant, 1997) tradujo su justificación al inglés:

> It doesn't receive any sunlight most of the time and when it does, the sun rays falls obliquely and without much vitality.

La Roma clásica recoge el legado de Grecia en muchos aspectos. No debería sorprendernos que los romanos heredaran también los principios del diseño solar. Vitruvius, el eminente arquitecto romano del siglo I a. C., escribió en sus *Diez Libros de Arquitectura*: "Los edificios deben cerrarse más que exponerse hacia el norte, y la parte principal debe orientarse hacia el más caluroso lado sur". Las casas romanas incorporaban un espacio que servía de 'caldera solar' conocida como el 'heliocaminus'. Este sistema captaba la energía solar y la distribuía por las estancias. El Panteón de Roma incorpora la radiación a través de su óculo en el centro de la cúpula y da fe de la importancia que los romanos otorgan a la luz solar. El acondicionamiento térmico a través de la energía solar no fue utilizado sólo en ámbito doméstico, también formó parte del diseño de edificios públicos como los baños de Ostia y Caracalla (Tatcher, 1965; Ring, 1996). Los romanos fueron también pioneros en la legislación de la zonificación solar para proteger el acceso a la luz solar por parte de los ciudadanos. Las quejas y demandas aparecieron pronto porque muchos propietarios no podían incorporar el 'heliocaminus' ya que el acceso solar quedaba obstruido. Ulpiano, un célebre jurisconsulto romano del siglo II d. C., decretó que el acceso solar debía ser defendido y garantizado. Este precedente asentó el derecho solar que más tarde fue incluido en el Código de Justiniano (Jordan & Perlin, 1979).

Un salto de gigante traslada la discusión sobre el diseño de la presencia solar hasta el periodo de la Revolución industrial. Durante la segunda mitad del siglo XVIII, Europa Occidental es testigo de enormes cambios asociados a la migración masiva desde las áreas rurales hacia los centros urbanos con el propósito de trabajar en las fábricas. En muchas ciudades de la Gran Bretaña y de otros países europeos, los trabajadores sólo podrán encontrar alojamiento en barrios convertidos en guetos con muy malas condiciones sanitarias. *Oliver Twist*, la novela de Charles Dickens, retrata las deplorables condiciones de vida de barrios pobres como sería el suburbio de Bermondsey en Londres. La inexistencia de cloacas sumada a la alta densidad y la baja exposición a la luz solar son causa de insalubridad y enfermedades (brotes de cólera, tifus, raquitismo, tuberculosis y otras enfermedades mortales). La primera epidemia del cólera en Inglaterra fue registrada en 1831 en la ciudad de Sunderland. Otras siguieron en Gran Bretaña, Alemania y en otros países europeos. En el siglo XIX, los técnicos implicados con las condiciones de sanidad urbanas reclaman cambios de actitud y, por primera vez en la historia británica, consiguen que el gobierno manifieste en el Public Health Act of 1842 su responsabilidad de proteger y salvaguardar la salud y el bienestar públicos. Años más tarde, las declaraciones de intenciones pasan a materializarse en propuestas urbanas. En 1876, Benjamin W. Richarson presenta los planos para una ciudad utópica llamada *Higeia*, o ciudad de salud. El proyecto incorpora un mayor número de espacios verdes y la obligatoriedad de acceso solar. Otra propuesta de planeamiento urbano llega con la publicación en 1902 del libro de Ebenezer Howard, titulado *Garden Cities of To-Morrow* (Howard, 1902). Su modelo de ciudad, permanentemente rodeado por un cinturón de tierra agrícola, pasó a ser conocido como la Ciudad Jardín. En torno a mediados del siglo XIX, la comunidad vinculada con el diseño empieza a propugnar las prácticas del buen diseño lumínico. La famosa enferma británica, Florence Nightingale, fue defensora de maximizar la luz solar en las viviendas y en las salas de los hospitales. Ella apuntó que los pacientes de las salas soleadas tenían mejor espíritu y eran más alegres que los de las áreas sin luz solar. Su afirmación la llevó incluso a sugerir el diseño de plantas de hospital para maximizar los espacios soleados.

La importancia de la luz natural crece cuando, en el año 1903, el Dr. Niels Finson recibe el Premio Nobel por demostrar que la luz solar puede curar la tuberculosis por idear un método de curación gracias a la radiación ultravioleta. Poco después, durante la primera mitad del siglo XX, el mundo de la arquitectura conoce una revolución que abraza la modernidad y niega las viejas maneras de diseñar edificios. Las nuevas técnicas constructivas, basadas en losas de hormigón soportadas por pilares, permitieron liberar a las fachadas de su función estructural. A partir de entonces, las fachadas podían proporcionar grandes superficies con ventanas y maximizar la luz natural y el aire fresco. Le Corbusier fue el máximo estandarte del Movimiento Moderno y promulgó una arquitectura radicalmente nueva, pensada para ofrecer al hombre moderno unas condiciones de habitabilidad notablemente mejoradas, que garantizarían la higiene, la salud, la ergonomía y el contacto con el medio natural. En 1926, Le Corbusier construyó la Villa Savoye en Poissy (Francia) que se convirtió en un icono de los preceptos que promulga esta nueva arquitectura. El ideario moderno fue también trasladado a la escala urbana. El mismo Le Corbusier propuso un diseño de ciudad utópica, La Ville Radieuse. La extrema modernidad de la ciudad apostaba por la edificación en altura para proporcionar alojamiento, trabajo, ocio y servicios a tres millones de habitantes sin interrumpir la continuidad de espacios verdes y garantizando el acceso solar en las edificaciones. La claridad ideológica del Movimiento Moderno y su gusto por la abundancia de la luz natural en los interiores pueden ser igualmente reconocidos en la arquitectura de Richard Neutra, Frank Lloyd Wright y Mies van der Rohe. En paralelo a estos nuevos conceptos, la industria de la iluminación artificial no deja de prosperar. La fuerte presión de sus interiores aleja paulatinamente a los interiores de su vocación de contacto con el exterior. El mundo de la iluminación artificial promueve las investigaciones que, de manera obsesiva, definen umbrales de ergonomía para garantizar la productividad en el trabajo. En ocasiones, las propuestas argumentan la necesidad de niveles de iluminación desorbitados (1200 lux). Una recomendación que vela más por favorecer el consumo y el negocio energético que por garantizar el confort lumínico de los usuarios. El siglo XX también es testigo de la creciente densidad de las ciudades. Nueva York pasa a ser icono de ciudad moderna y muchas otras ciudades apuestan por el crecimiento en altura y por la alta densidad reduciendo de manera drástica la posibilidad de presencia solar en los interiores. Cada vez más, el acondicionamiento artificial gana terreno al natural.

Sin embargo, la crisis del petróleo del año 1973 advierte que el modelo energético es erróneo y que conviene reconducir la situación, promover la conservación de la energía y el uso de energías renovables, cediendo el protagonismo al potencial solar. La arquitectura solar es una respuesta directa a la crisis del petróleo y su popularidad crece al final de los setenta, particularmente en el suroeste americano donde abunda la luz solar. Los principios de diseño solar y pasivo ganan protagonismo y adaptan sus estrategias a las diferentes condiciones climáticas en el continente americano y fuera de este (Olgyay, 1963). Sin embargo, pese a los esfuerzos, el modelo energético avanza lentamente y, a día de hoy, sigue estando basado en la explotación de los combustibles fósiles. Pese a las consignas de conservación de la energía, la iluminación natural es raramente utilizada como una estrategia clara para reducir el consumo. Las oficinas y los edificios comerciales siguen estando iluminados artificialmente. Los proyectos que incorporan etiquetas supuestamente verdes o ecológicas siguen siendo una novedad y los que incorporan el diseño de la luz natural quedan restringidos a usos especiales como sería el caso de algún museo. Frecuentemente, los ocupantes siguen conviviendo con entornos iluminados artificialmente, alejados de los beneficios que les aporta la luz natural.

El siguiente capítulo verifica cuáles son las normas que rigen la presencia de la luz solar en la arquitectura. El propósito es detectar sus virtudes y deficiencias para, más tarde, abordar los esfuerzos de los investigadores por completar las normas con nuevo conocimiento.

2.4.2. La legislación actual y sus límites

El ahorro energético es un argumento que utilizan en su favor los defensores de la luz natural. El Electric Power Research Institute (EPRI), afirma que, en el sector comercial estadounidense, la electricidad representa el 37% del consumo energético (EPRI, 1995). Pese a la crisis del modelo energético, este argumento parece insuficiente para dar lugar a normas que regulen adecuadamente la presencia de la luz solar en los interiores. Sin cesar en el empeño, los defensores de la luz natural buscan nuevos argumentos y los encuentran en sus beneficios para la salud de los ocupantes, ya descritos en el subcapítulo 2.3.2. La legislación de la presencia de la luz solar afronta una gran barrera si se plantea en los términos que impuso la iluminación artificial, basados en garantizar unos niveles mínimos de iluminancia. El dinamismo de la luz natural dificulta la redacción los estándares basados en la imposición de unos niveles lumínicos mínimos, pensados desde la óptica de la iluminación artificial. Aunque los métodos de cálculo aplicados permiten una precisión elevada, sus resultados nunca pueden ser garantizados ya que dependen de los datos de partida obtenidos gracias a los promedios estadísticos de las estaciones meteorológicas. Pese a las dificultades, la observación del panorama internacional permite reconocer algunas tentativas legislativas (Julian, 1998). Haciendo referencia a este trabajo, Boubekri clasificó estas tentativas en tres grupos de los cuales este subcapítulo hace eco (Bouberkri, 2004b).

En primer lugar, la clasificación hace referencia a casos de legislación que regulan la cantidad de luz natural. La iluminancia mínima es uno de los parámetros utilizados. En Estados Unidos, el IESNA (Illuminating Engineering Society of North America) no se pronuncia al respecto cuando la fuente de luz es natural. En cambio, el BOCA (Building Official Code Administrators) sí lo hace y estipula que: "the standard for natural light for all habitable and occupiable rooms shall be based on 250 foot-candles (2691 lux) of illumination on the vertical plane adjacent to the exterior of the light-transmitting device in the enclosure wall and shall be adequate to provide an average illumination of 6 foot-candles (64.58 lux) over the area of the room at a height of 30 inches (762 mm) above the floor level." La norma estimula que la iluminación artificial puede corregir situaciones de insuficiencia lumínica. En Canadá, el Department of Public Works recomienda un nivel medio de 200 lux a lo largo del perímetro de un espacio de oficina a una profundidad de 3 metros durante el 80% de las horas de trabajo, de las 8 a las 17 horas (Archer, 1998; Wotton, 1998). Sin embargo, estos son valores recomendados y no obligatorios. En Alemania, la norma DIN 5034-4 ofrece también niveles recomendados de iluminación natural que dependen de la exigencia visual de la tarea realizada. Una segunda estrategia para regular la cantidad de la luz natural en los interiores es el uso de factores que describen la presencia de la luz en función de la proporción de cielo visible (por las ventanas o los interiores), teniendo en cuenta las obstrucciones que provoca el entorno. En Francia, el *Cahier des Recommandations Techniques de Construction*, (Ministère de l'Éducation Nationale,

1997) recomienda en aulas escolares un Daylight Factor mínimo de 1.5% bajo condiciones de cielo cubierto. En el Reino Unido, la misma regulación proponía un 2% pero fue descartada ya que implicaba grandes superficies acristaladas que, como contrapartida, provocaban otros problemas de tipo lumínico y térmico. Otra recomendación en el mismo país es la promovida por el Building Research Establishment (British Standard 8206, 1982). La norma define la cantidad de luz que una ventana debería recibir recomendando un 27% de Vertical Sky Component, un valor propio de los contextos urbanos de baja densidad pero que difícilmente puede ser garantizado en los centros urbanos.

En segundo lugar, otro tipo de normas repercuten en la presencia de luz natural a través de la definición del tamaño de las ventanas. En la mayoría de los casos, estas normas no están pensadas exclusivamente desde la necesidad de iluminación. Su función es dar respuesta a múltiples funciones. Entre las cuales, la necesidad de ventilación o la seguridad frente a incendios. En algunos casos, los códigos prescriben un porcentaje de ventana en función del área de la fachada: en Inglaterra, un 20% en el caso de habitaciones de profundidad menor a 14 metros (Department of Environment, 1971; Health & Safety Commission, 1992), 35% en oficinas y 25% en edificios institucionales (Littefair, 1999b). Sin embargo, en la mayoría de los casos, los códigos regulan el porcentaje de ventana en relación al área de la habitación: en Australia, un 10% en el caso de edificios residenciales (Australia Community Development Project, 2002); en Japón, un 14% en viviendas y entre el 20 y el 40% en el caso de otros edificios de ocupación continua (colegios y hospitales), quedando liberados de mínimos exigibles en las oficinas y las industrias (Koga y Nakamura, 1998); en Estados Unidos, un 8% en cualquier habitación prevista para el uso humano (BOCA, 1990). En este último caso, la norma sí que explicita su vocación por garantizar la iluminación natural. Con el mismo propósito, en Alemania, la norma *DIN 5034-4 Daylight in interiors – Simplified regulation for minimum window sizes* prescribe los tamaños de las ventanas para una buena iluminación natural en función de varios tamaños de habitación.

Por último, en tercer lugar, están las normas de accesibilidad solar. Su planteamiento es a escala urbana y afecta la volumetría de los edificios. Estas normas son las que, en primera instancia, posibilitan o coartan la incidencia solar sobre las fachadas, y así, las posibilidades de iluminación natural. Sus repercusiones son tan relevantes que podría decirse que son las normas más importantes. Los municipios son los responsables de estas normas lo que da lugar a una gran diversidad según el contexto en el que se inscriben. Las condiciones climáticas juegan un papel fundamental pero no hay que olvidar que estas normas deberán sobretodo lidiar con los fuertes intereses económicos privados de los propietarios del suelo en los centros urbanos. El caso de Nueva York es un referente histórico cuyo concepto de zonificación en altura de la envolvente dio lugar a la característica forma retranqueada que más tarde sería símbolo de los edificios de Manhattan. Otra ordenanza más reciente, votada en 1985, es la estricta *Proposition K* de San Francisco, también conocida como la *Sunlight Ordinance* (Phillips, 1985; Kwartler and Masters, 1984). Su redacción exige, durante todo el año, el acceso solar a lo largo del día en determinados espacios exteriores, parques y calles. En Japón, las ordenanzas relativas al acceso solar llegaron más tarde que en los Estados Unidos. Un ejemplo es el *Japanese Building Standard Act* de 1977 que permitía a las municipalidades denegar permisos de construir por encima de ciertas alturas que arrojasen sombra por encima de un número concreto de horas prescritas (Koga and Nakamura, 1998; Julian, 1998).

Ninguno de los códigos mencionados basa su formulación en la regulación de la presencia de la luz solar en los interiores desde el punto de vista lumínico. Sus recomendaciones no hacen referencia explícita a cómo juzgar los parches solares reflejados en las superficies, priorizando el confort visual de los ocupantes. El juicio requiere una concepción del problema alejada de las prácticas más habituales. La distribución de la luz incidente en el espacio no sería el único y exclusivo objeto de la evaluación. La relevancia estaría más bien puesta en la visión que tienen los usuarios de la luz manifestada tras su reflejo sobre las superficies. Esta concepción exigiría cambiar las estrategias y las normas que regulan en diseño con el fin de alejarse de los planteamientos estrictamente cuantitativos basados en una luz incidente, que el usuario no ve, y propondría el reto de trabajar desde aspectos cualitativos vinculados a la luz visible, la reflejada. Aceptar el reto exige incluso “cambiar” las unidades lumínicas de trabajo (cd/m2 en lugar de lux) y dotarse del instrumental de medición acorde (medidores de luminancias, o cámaras CCD, en lugar de luxómetros). A fecha de hoy, sólo la investigación científica y algunos proyectos arquitectónicos singulares (museos) tratan la cuestión. Los siguientes subcapítulos describen la contribución de algunos de los trabajos de investigación y sitúan la aportación de la tesis en relación a éstos.

2.4.3. Los parches de sol y su control físico: tamaño, posición y duración

Los procedimientos científicos acostumbran a estudiar separadamente los diferentes factores que caracterizan un fenómeno. El estudio de un factor aislado del conjunto determina si su influencia es relevante para explicar el fenómeno. El caso que ocupa a este capítulo es el diseño de presencia solar en los interiores. Dicha presencia puede ser descrita como la manifestación de unos parches de sol caracterizados por su intensidad, tamaño, posición y duración. Diferentes trabajos de investigación abordan los efectos concretos de las variaciones de cada una de estas características. La misión de este subcapítulo es poner en relación la contribución de estos trabajos atendiendo sucesivamente a la reacción de los usuarios frente al tamaño, la posición y la duración de los parches solares.

Factor 1: Tamaño

En 1991, Boubekri, Hulliv y Boyer publican el artículo titulado *Impact of Window Size and Sunlight Penetration on Office Workers' Mood and Satisfaction – a Novel Way of Assessment (*Boubekri, 1991*).* El estudio investiga el impacto del tamaño de la ventana y de la penetración de diferentes cantidades de luz solar sobre la respuesta emocional y el grado de satisfacción de los ocupantes. A diferencia de otros estudios, la penetración solar se mide en términos de tamaño de las áreas soleadas y, por lo tanto, como estímulo visual. El estudio fue realizado en un despacho de tamaño típico gracias a la participación de 40 trabajadores que evaluaron las condiciones ambientales desde dos puntos de vista, uno frontal y el otro lateral respecto a la ventana. Durante el estudio, realizado en el mes de agosto, cuatro tamaños de ventana fueron evaluados (10%, 20%, 40%, 60% del tamaño de la fachada). La cantidad de penetración solar fue considerada como un porcentaje del área total del suelo dando lugar a cuatro cantidades (3.5%, 15.2%, 30% y 45%). Los resultados permitieron concluir que el tamaño de la ventana no afectaba significativamente el estado emocional de los ocupantes o su grado de satisfacción. En cambio, la penetración solar afectaba significativamente la sensación de relajación. El tamaño óptimo de las áreas soleadas correspondía a proporciones entre el 15 y el 25% del área total del suelo. Entre esos márgenes, los trabajadores reconocían sensaciones positivas que les transmitían relajación. Las reacciones positivas disminuían en las situaciones extremas y sólo devenían molestas cuando superaban una proporción del 40%.

Factor 2: Posición

Wang y Boubekri son autores de dos artículos en los que abordan la influencia de la posición de los parches de sol en el confort. Ambos artículos son el resultado de un mismo experimento realizado en el interior de un aula de la University of Illinois, ubicada en Urbana-Champain, a unos 200 km al sur de Chicago. La zona climática es relativamente fría (latitud 40ºN), con una cantidad de luz solar moderada a lo largo del año. La particularidad del trabajo es que extrae las conclusiones a partir del comportamiento de los usuarios que, según afirman los autores, sufren cambios en función de las condiciones lumínicas. Ante la presencia de luz solar, el experimento evalúa las reacciones de los usuarios en función de su eficiencia cognitiva, de su humor y de las preferencias que expresan en cuanto a la distribución del mobiliario. Los resultados comparan las respuestas de los usuarios que ocupan tres filas de asientos de un aula de tamaño reducido (6.2 m x 4.9 m). El experimento incorpora la evaluación de la repercusión de otros dos factores psicológicos: la privacidad (ante miradas ajenas) y el control (visual sobre el espacio). La hipótesis de partida es que la distancia entre el ocupante y el parche de sol en el suelo es una variable importante, que repercute sobre el comportamiento. El objetivo es descubrir una ‘distancia óptima’ a través del análisis de las reacciones de los usuarios. Considerando lo placentera o molesta que puede ser la luz solar, la hipótesis prevé que la distancia preferida será cerca del parche de sol pero no dentro de él, especialmente cuando los usuarios desarrollan una tarea visual.

El artículo titulado *Design Recommendations Based on Cognitive, Mood and Preference Assessments in a Sunlit Workspace* (Wang 2011) analiza una parte de los resultados. Inesperadamente los factores secundarios del estudio (privacidad y control) acostumbran a repercutir en los resultados y hacen menos evidente la reacción de los usuarios en relación a la distancia que les separa del parche solar. En cuanto al humor se refiere, los autores comentan que decae menos cuando los ocupantes tienen un alto grado de control. Por otra parte, el humor también decae menos en el caso de los sujetos que ocupan las posiciones cercanas al parche de sol y con una mejor vista hacia el exterior. El usuario sentado dentro del parche de sol registra la peor decaída. En relación a la eficiencia de los usuarios al realizar su tarea visual, el estudio no consigue demostrar la correlación con la posición del parche solar. Los factores secundarios vuelven a ser los significativos ya que los usuarios que registran los mejores resultados son los que ocupan la fila trasera con mayor control sobre el espacio y la puerta. Finalmente, el artículo publica las preferencias que los usuarios expresan sobre un dibujo en relación a la posición y dirección de una mesa de trabajo en una oficina ideal para un solo trabajador. La mayoría de los sujetos escoge sentarse cerca y dentro del parche solar. Muchos escogen sentarse en paralelo a la fachada pero no son pocos los que eligen dar la espalda a la ventana condicionados por el deseo de privacidad de sus tareas y la atención o control de la puerta. Considerando las preferencias expresadas y las variaciones en eficiencia y el humor, los autores concluyen que la ‘zona óptima’ está ubicada muy cerca del parche de sol, posibilitando la privacidad y el control dentro del espacio y posibilitando las vistas. Los autores dibujan la alternativa ideal en la que la mesa se ubica en paralelo a la fachada, sin que el parche de sol caiga sobre la mesa en ningún momento del año y permitiendo el control visual de la puerta. Esta pauta permite a los autores extrapolar su solución a una oficina de tamaño similar pero con dos puestos de trabajo y, después, a otra de tamaño mayor con ocho puestos de trabajo.

El mismo experimento da lugar a un segundo artículo publicado bajo el título *Investigation of Declared Seating Preference and Measured Cognitive Performance in a Sunlit Room* (Wang, 2010). Los autores publican nuevos datos y motivos de discusión. En relación a las preferencias en la distribución del mobiliario en función del uso, además del caso de la oficina, los sujetos expresan sus preferencias en relación a dos nuevos casos: la posición de una mesa de reuniones o la de dos sillones con reposabrazos. Los sujetos justifican sus decisiones completando unas encuestas en las que señalan las causas que motivan su elección. En el caso de la mesa de reuniones, la mayoría de los usuarios escoge una posición central, sin fomentar la vista a través de la ventana o la cercanía respecto a los parches de sol. Las dos razones más habituales son la centralización y la fluidez de la circulación en la habitación. En el caso de los dos sillones, hay división de opiniones aunque el mayor número ubica los asientos sobre el parche de sol y mirando a través de la ventana. Las dos razones que privilegian son las vistas y la relajación. En el caso de la mesa de trabajo, su posición y dirección fueron publicadas en el artículo anterior. Este artículo añade la justificación. Los tres motivos que más se nombran son el confort visual, el control y las vistas, aunque la iluminación y la luz solar también aparecen destacadas.

En el segundo artículo los autores expresan unas conclusiones extraídas a través de los resultados de los dos artículos. Ellos indican que la hipótesis de partida que vinculaba la eficiencia con la distancia respecto al parche solar (y a una deseada posición óptima) no ha podido ser demostrada. En cambio, los resultados sí que validan la hipótesis que indica que la localización del parche solar y de la ventana, asociada a las características de las actividades de los ocupantes en la habitación, afectan la manera en la que los usuarios aprecian y usan una habitación soleada. La privacidad y el control aparecen como factores ocultos. Por otra parte, el deslumbramiento visual (un problema comúnmente discutido y asociado a la luz solar) no afecta la eficiencia en la medida que los sujetos mismos y los arquitectos pensarían que lo hace. A continuación, los autores hacen referencia a las limitaciones del estudio que deberían ser mejoradas con nuevas investigaciones. El número de sujetos es reducido e impide discernir la influencia de otros factores como el género y la ocupación profesional. Otro handicap es que el estudio sólo considera las reacciones durante una estación (primavera) y vinculadas a una única zona climática.

Factor 3 - Duración:

El artículo *Recommendations for the Admission and Control of Sunlight in Buildings* aborda la cuestión de la duración de la presencia solar en los interiores (Ne’eman, Light, & Hopkinson, 1976). La propuesta es fruto del ya mencionado (capítulo 2.3.1) proyecto de investigación titulado *Sunlight in Buildings* (Hopkinson & Watson, 1973/74). Los autores justifican su elección de la regulación del factor tiempo debido a la contribución de otros trabajos (no especifican cuáles) que ponen de manifiesto que la apreciación de los usuarios es más sensible a la duración de la presencia de los parches solares que a su intensidad o tamaño. El artículo recomienda entonces unos tiempos mínimos y máximos de presencia solar anual para satisfacer las actividades que ocurren en los interiores de cuatro tipos de edificios (viviendas, escuelas, oficinas y hospitales). Este requerimiento horario está basado en el estudio estadístico de la primera parte del proyecto de investigación que estudia las preferencias los usuarios en función de los usos (Ne'eman, Craddock, & Hopkinson, 1976).

En términos generales, los autores indican que conviene que el diseño de los elementos fijos pretenda la presencia solar siempre que sea posible. En caso de que dicha presencia fuese excesiva, los elementos de control servirían para la regulación. Para recomendar la duración específica de la presencia solar según la actividad, los autores parten de la afirmación de que cuanto más confinada está la actividad, más severos son los efectos adversos sobre los usuarios. Contrariamente, cuanta mayor libertad disfrutan los usuarios para escoger su visión y posición en relación al sol, menos negativos son los efectos que pueda causar el sol. Consecuentemente, los autores establecen unas recomendaciones en relación al patrón actividad-posición-dirección de la visión basadas en tres patrones: A (posición fija, sedentaria y recostada; dirección de la visión restringida), B (posición variable, sedentaria con movimiento intermitente; dirección de la visión variable) y C (activa). Seguidamente se proponen tablas que asocian el número de horas de penetración solar en función del uso y del patrón de actividad (A, B o C). El repertorio de horas se especifica de dos maneras: número de horas totales anuales (mínimo 400 o 500; máximo 600 horas; y casos particulares en que no se requiere o se excluye) y, para casos particulares, el número de horas totales anuales entre las 9:00 y las 16:00 horas (mínimo 400 y máximo 600). Sorprendentemente, una lectura en detalle de las tablas no muestra notables variaciones en función de los tres diferentes patrones (A, B o C). Además, el trabajo propone consideraciones respecto a los dispositivos de control de la luz solar en función de los tres patrones. Los autores definen tres posibilidades: P ('control preferred'), R ('control required – preferred externally') y E ('control essential – required externally').

Finalmente, el artículo ofrece un método para definir el 'ángulo de apertura' de las ventanas en función de las horas requeridas. El método se basa en una carta solar estereográfica en la que se corrige la radiación teórica máxima por una radiación previsible en función de los datos climatológicos de una estación meteorológica (Kew, Londres). Un comentario indica que estos datos se han comparado con los de numerosas estaciones meteorológicas del Reino Unido y que la desviación máxima es leve (15%); por tanto, sería admisible utilizar esta carta para la totalidad del territorio.

2.4.4. Control de los parches de sol: parámetros e índices

En 1977, Ne'eman publica *Sunlight Requirements in Buildings – II. Visits of an Assessment Team and Experiments in a Controlled Room* (Ne'eman, 1977). Los experimentos de este trabajo también forman parte del proyecto *Sunlight in Buildings* (Hopkinson & Watson, 1973/74). Su propósito es correlacionar las respuestas subjetivas de los usuarios con las mediciones de ciertas cantidades físicas: luminancia del cielo y de los espacios interiores, índices de contraste, índice de deslumbramiento y parámetros térmicos. Al finalizar el artículo, Ne'eman afirma que la correlación no puede ser demostrada en ningún caso; sin embargo, añade que estos resultados no significan que no exista la correlación sino que los métodos utilizados no son los adecuados para revelarla. El subcapítulo actual describe y comenta los dos experimentos que justificaban sus comentarios.

A diferencia del trabajo anterior, *Sunlight Requirements in Buildings – I. Social Survey* (Ne'eman, 1976), la metodología de esta segunda entrega compara las respuestas subjetivas de un reducido número de observadores expertos con las mediciones simultáneas anteriormente enumeradas. En primer lugar, el trabajo analiza las visitas a ciertos edificios en unos momentos en que existía presencia solar. Una vez en el interior, las condiciones lumínicas no pudieron modificarse, no fueron extremas y no sirvieron para juzgar las posibles situaciones molestas. Esta situación dio lugar a un segundo experimento en una habitación controlada que permitiría provocar unas situaciones ambientales susceptibles de causar molestia, facilitando así el propósito de correlación.

Visitas: El equipo de evaluación visita dos hospitales, una escuela y tres universidades. Los observadores evalúan 35 posiciones sentadas y cumplimentan 278 formularios. Como ya se ha anticipado, según ellos, las condiciones ambientales de este experimento están demasiado alejadas de provocar molestia y no son útiles para relacionar las mediciones con los grados de molestia. Como alternativa, los autores sugieren tres conclusiones no cuantitativas, es decir, sin parámetros numéricos. La primera hace referencia al confort general e indica que es igualmente dependiente del confort visual que del térmico. Las dos siguientes abordan la cuestión del deslumbramiento. La segunda afirma que el deslumbramiento asociado a la tarea visual parece ser la respuesta más significativa al confort visual. Las condiciones experimentales describen que la tarea visual consiste en que el usuario rellene la encuesta, es decir, que realice anotaciones en un papel apoyado sobre una mesa. A través de la experiencia adquirida tras las mediciones de esta tesis, es posible afirmar que, en estos casos, el campo visual está casi totalmente ocupado por la visión de la mesa. Así, la causa del deslumbramiento no es el excesivo contraste de luminancias (parches de sol brillantes respecto a un fondo: “Discomfort Glare”) sino la excesiva radiación directa sobre el plano de trabajo (iluminancia muy alta: “Veiling Reflections”). En la tercera y última conclusión vuelven a nombrarse las molestias que causa el deslumbramiento. Concretamente, la conclusión afirma que, cuanto más alejados están los parches solares del observador, menor es el efecto del deslumbramiento. Esta afirmación es cierta y, de hecho, está considerada en la definición de la formulación del “Discomfort Glare”. Sin embargo, los experimentos de esta tesis demostraran más adelante que no debería perderse de vista la luminancia del fondo cuando pretende evaluarse el riesgo de deslumbramiento. Esta luminancia puede ser tan influyente como la luminancia de los parches de sol.

Habitación controlada: Particularmente, este segundo experimento utiliza una sala en la que se acomodan tres posiciones de trabajo asociadas a tres mesas. La primera mesa está ubicada en ángulo recto con una pared lateral del espacio, mirando hacia la única ventana, aproximadamente centrada en la fachada. Las dos otras mesas están junto a la ventana, enfrentadas entre ellas, con la ventana a un lado. La ventana está orientada hacia el oeste. Así, cuando levanta la mirada, uno de los dos observadores ve unas porciones de cielo pertenecientes al sur, con el riesgo de que el sol o su halo estén dentro del campo visual, causando un alto riesgo de deslumbramiento. Las mediciones de esta tesis demuestran más adelante que este factor es fundamental. Del mismo modo, lo especular que sea la reflexión sobre la mesa (a menudo elevada debido a los barnices o a las pinturas plásticas y a las superficies pulidas) también es importante en estos casos. En cambio, desde la segunda mesa junto a la ventana, el usuario ve unas partes de cielo correspondientes al norte y, por tanto, con unas luminancias más bajas que suponen un menor riesgo de deslumbramiento. En este experimento, la elección de la hora del día permite escoger las condiciones lumínicas específicas para cada posición (muy variables para una ventana con orientación oeste que implica rápidos cambios en la altura y el azimut solares). Los cambios de temperatura también pueden manipularse a través de la climatización artificial. Estas dos variables justifican que el autor indique que el experimento ocurre en una “habitación controlada”. En cuanto a estación del año, el texto no ofrece detalles y tan sólo indica que a partir de las 14:00 inicia el acceso solar. Esta información no es suficiente para deducir con exactitud la fecha o la estación. En cuanto a la dirección de las miradas parece que los observadores alternan la mirada hacia el formulario sobre la mesa con la mirada hacia dos puntos señalados: uno llamado “x” sobre la ventana y otro llamado “y” entre las dos mesas. Si el primer experimento no determinaba correlaciones, en este segundo caso sucede lo mismo. Las respuestas subjetivas y las mediciones de las luminancias de las superficies no dan muestras de coincidencias. Tampoco existe una relación entre las respuestas de los usuarios y los coeficientes que describen el contraste entre las superficies o con el cálculo del índice de deslumbramiento correspondiente a los diferentes campos visuales. Cabe decir que el artículo no especifica cuál es el índice utilizado. Además, conviene observar que la precisión del cálculo está muy alejada de los métodos utilizados más adelante por esta tesis. Los autores de este artículo calculan las luminancias promedio de las superficies con muy pocas mediciones puntales (tres para el cielo). En cambio, en esta tesis, el cálculo integra en valor individual de la luminancia de cada píxel de una imagen HDR.

Pese a que el artículo no es capaz de establecer conclusiones que relacionen las mediciones y las valoraciones de los usuarios, los autores incluyen otro tipo de conclusiones bastante generales y, en algunas ocasiones, obvias y escasamente argumentadas. La enumeración es la siguiente:

- El confort térmico no influye en las evaluaciones visuales.

- La cantidad de penetración solar es un factor clave para el confort térmico y visual. En este trabajo, la cantidad está más asociada a la profundidad de la penetración que a su intensidad.

- La valoración no identifica diferencias substanciales por géneros (hombres y mujeres).

- A los usuarios no les gusta la presencia de la luz solar en su “vecindad”. Son especialmente sagaces para evitar el sol reflejado sobre su superficie de trabajo o incidiendo en sus ojos. El experimento confirma lo que es bastante obvio, que el sol incidiendo en los ojos es causa de un deslumbramiento intolerable.

El último punto describe muy ambiguamente la posición de los parches solares refiriéndose a ella como un cierto grado de “vecindad”. Como se ha visto en los apartados anteriores, existen trabajos que ponen mucho más esmero en estudiar esta cuestión (Wang, 2010, 2011). Otra cuestión que no hay que olvidar es el reducido número de usuarios de estos experimentos. Algunas de las conclusiones se extraen con las respuestas de tan sólo 12 sujetos. El número parece insuficiente para dar lugar a conclusiones tan generales.

Comentario final y vínculo con la tesis:

Como los mismos autores reconocen, el procedimiento experimental desvelado en el último artículo no resuelve con éxito la correlación entre las reacciones de los usuarios y los parámetros numéricos. Pese a ello, los autores expresan que la correlación no es descartable y apuntan que el error está más bien en su metodología de trabajo. Siguiendo con el mismo propósito de correlación, esta tesis plantea profundizar en los efectos causados por los parches solares. El uso de los índices de deslumbramiento es el punto de partida ya que consideran, simultáneamente, a través de una única fórmula de expresión logarítmica (correspondiente a la sensibilidad logarítmica del usuario frente a las energías), la intensidad, el tamaño y la posición de los parches solares. Para la definición de una norma completa, tan sólo faltaría la repercusión de la duración que, al no poder quedar incluida de manera coherente en esta formulación, debería considerarse aparte. Pensar en una norma que defina la duración de la presencia solar en los interiores y que obligue a la comprobación de sus efectos lumínicos (utilizando los índices de deslumbramiento) y térmicos no parece inaccesible. Christoph Reinhart y Jan Wienold (2011) proponen un método para permitir una verificación dinámica y simultánea de los dos efectos. La contribución de esta tesis aporta una visión complementaria en cuanto a la validez de los índices de deslumbramiento ante las situaciones más críticas, dictadas por la posición de un usuario dentro de un espacio, la dirección de su mirada en relación a las ventanas y la orientación de la fachada que justificaría los valores de las luminancias exteriores e interiores.

Capítulo 3: Métrica del deslumbramiento molesto

Chapter 3: Metrics of discomfort glare

At the beginning of the thesis, the note to the reader mentions that this third chapter has been written in Spanish. Below, the English translation of its introduction (subchapter 3.1) provides a summary of its content:

Glare is the uncomfortable effect on vision that may cause brightness (luminance) within the visual field. A correct understanding of the phenomenon requires distinguishing between three types of glare: disability glare, discomfort glare and veiling or glare reflections. The first type refers to the presence of excessive brightness that saturates the optical capacity of the eye. The second type is linked to the vision of excessive contrast between the brightest surfaces and the rest of the scene. The third type warns of inappropriate contrast on computer monitors.

Although occasionally there may be cases of disability glare, discomfort glare is the most frequent in the lighting (natural and artificial) of interiors (Hopkinson & Kay, 1969). Consequently, the formulation of the glare indices, which are applicable to the assessment of the quality of indoor lighting, is mainly linked to discomfort glare and therefore with the risk of excessive contrast of luminances.

The concretion of the formulation of the discomfort glare indices faces a considerable challenge as it seeks to anticipate the reaction of the visual perception of users, partly subjective. During decades of research, the proposals of numerous glare indices have succeeded each other, without having ever reached a resounding agreement on the validity of a unique index. The aim of this chapter is to describe the most recognized indices and inform the reader of the discussions that they have provoked.

Since the evaluation of contrast is the matter, the starting point shared by many formulations is the assessment of the effect of the glare sources (Ls) compared to the *rest of the scene (Lb). Furthermore, since it describes the reaction of a human sense, a logarithmic function appears as the most appropriate in many cases. The expression of the formula is as follows* (CIE, 1983; Wienold, 2010):

$$G = \left(\frac{L_s^e . \omega_s^f}{L_b^g . f(\Psi)} \right) \tag{3-1}$$

Where:

- *The glare constant G expresses the predicted sensation and e, f and g are weighting exponents, while $f(\Psi)$ is a complex function of the displacement angle. The other parameters are:*
- *The luminance (L_s) of the glare source. In the case of windows: the luminance of the sky (or other bright surfaces) as seen through the window (the brighter the source or sky, the higher the index);*
- *The solid angle subtended by the source (ω_s). In the case of windows: the apparent size of the visible area of sky at the observer's eyes (the larger the area, the higher the index);*
- *The angular displacement (Ψ) of the source from the observer's line of sight. In the case of windows: the position of the visible sky within the field of view (the further from the centre of vision, the lower the index);*
- *The general field of luminance (L_b) controlling the adaptation levels of the observer's eye (also called background luminance). In the case of windows: the average luminance of the room excluding the visible sky (the brighter the room, the lower the index).*

In the search for greater degree of reliability of the formula, the size of the source appears as a critical factor. Its influence is such that it ends up causing a split between the formulas that evaluate artificial lighting (small sources) and those that intend to be specific for the assessment of natural light (large sources). However, this is always an issue of continuous debate. Often, the research works judge that the formulas related to daylight do not offer good response and that they continue being more appropriate for the evaluation of small sources (e.g. BGI). Some formulas validated for the assessment of artificial lighting pretend to be applied also for the assessment of daylight (e.g. CGI). The reason is the will to standardize a single method of calculation, *as well as enable the assessment of scenes simultaneously lit by artificial light and daylight, without discarding sunlight in some cases (e.g. DGI_N).*

The second critical element is the definition of those luminances that are object of comparison with the luminances of the sources of glare. Regarding this aspect, there is also divergence of opinions. On one hand, certain formulas (e.g. BGI, DGI and UGR) decide to establish the comparison with the background luminance (Lb), excluding the glare sources, emphasizing the evaluation of the contrast between the brightest surfaces and the remaining surfaces (background). On the other hand, other proposals consider that it is more appropriate assessing the effect of the brightest surfaces in relation to the adaptation of the eye facing the whole vision (e.g. CGI, DGI_N and DGP). In this case, the vertical illuminance at the observer's position (Ev), which includes the effect of the glare sources, describes the adaptation of the eye and becomes a relevant factor that even motivates significant changes in the formulation in respect to the primitive proposals for the glare indices.

This chapter will notice that the comparison between the different indices is often difficult to argue since their definition initiates from experimental conditions that are notably different. Some indices (e.g. BGI and DGI) are validated through front views directed towards a bright artificial surface that simulates a window (a fact that raises criticism when these indices intend to be validated to measure the effect caused by the windows). Other indices (e.g. DGP) base their definition on the study of real cases in which the observer does not direct his/her gaze towards the glaring surfaces; he/she fixes his/her attention on a vertical work surface (computer screen) that occupies the centre of vision and implies an horizontal gaze and certain global vision of the space.

Some dilemmas have just had been explained thanks to this introductory summary. These dilemmas and some others are the subject of further comment in the following subchapters. Each one offers a description and a detailed analysis of each of the most relevant indices. The eight indices that are part of this study are listed below:

- *BRS Glare Equation (BRS o BGI)*
- *Cornell Equation o Daylight Glare Index (DGI)*

- *CIE Glare Index (CGI)*
- *Unified Glare Rating (UGR)*
- *Visual Comfort Probability (VCP)*
- *New Daylight Glare Index (DGI_N)*
- *Predicted Glare Sensation Vote (PGSV)*
- *Daylight Glare Probability (DGP)*

The subchapters related to DGI and DGP indexes will deserve further comment and therefore extension. These two indices will be selected to become part of the methodology that will be useful to assess the case studies. The choice of these two indices is due to two reasons. The first reason is the support they have deserved through experiments in which their validity was tested. The second reason is that these two formulations are based on the two different approaches that have been mentioned above. The first one (DGI) highlights the relevance of the background luminance (Lb) and, therefore, the analysis is based on the visual contrast. The second one (DGP) emphasizes the effect of vertical illuminance at the observer's position (Ev) and, therefore, the visual adaptation of the observer to the entire scene. As is well known, these two indexes consider the assessment of glare defined as 'discomfort glare' but it is possible that the case studies test their reliability under more extreme light conditions, those that correspond to glare defined as 'disability glare', resulting of the presence of sunlight in the scenes. In fact, the boundary between 'discomfort glare' and 'disturbing glare' is not always so obvious to distinguish. For this reason the results of some of the formulas used for artificial lighting, occasionally, seem to be close to the assessment of 'disability glare'.

3.1. Introducción

El deslumbramiento es el efecto incómodo para la visión que pueden ocasionar los brillos (las luminancias) dentro del campo visual. Una correcta comprensión del fenómeno requiere distinguir entre tres tipo de deslumbramiento: perturbado, molesto y por velo o reflexión. El primero hace referencia a la presencia de un brillo excesivo que satura la capacidad óptica del ojo. El segundo está vinculado a la visión de un contraste excesivo entre las superficies más luminosas y el resto de la escena. El tercero advierte de un contraste inapropiado sobre los monitores.

Aunque ocasionalmente pueden darse casos de deslumbramiento perturbador, el deslumbramiento molesto es el más frecuente en la iluminación (natural y artificial) de interiores (Hopkinson & Kay, 1969). Consecuentemente, la formulación de los índices de deslumbramiento aplicables a la valoración de la calidad de la luz en interiores está principalmente vinculada con el deslumbramiento molesto y, por tanto, con el riesgo de un contraste de luminancias excesivo.

La concreción de la formulación de los índices de deslumbramiento molesto afronta una dificultad notable ya que pretende prever la reacción de la percepción visual de los usuarios, parcialmente subjetiva. Tras décadas de investigación, las propuestas de numerosos índices han ido sucediéndose sin que haya habido nunca un acuerdo rotundo sobre la validez de un único índice. El objetivo de este capítulo es describir los índices más reconocidos e informar al lector de las discusiones que han provocado.

Puesto que de la evaluación del contraste se trata, el punto de partida compartido por muchas formulaciones es la evaluación del efecto de las fuentes de deslumbramiento (Ls) comparada con el resto de la escena (Lb). Además, puesto que describe la reacción de un sentido humano, una función logarítmica aparece como la más apropiada en muchos casos. La expresión de la fórmula es la siguiente (CIE, 1983; Wienold, 2010):

$$G = \left(\frac{L_S^e . \omega_s^f}{L_b^g . f(\Psi)} \right) \tag{3-1}$$

Donde:

- La constante de deslumbramiento G expresa la predicción de la sensación. Los exponentes e, f y g otorgan un peso específico a cada cantidad física. $f(\Psi)$ es una función compleja que pondera la presencia de la luz en función del ángulo de desplazamiento en relación al centro de la visión. Los parámetros restantes son:
- La luminancia (L_s) de la fuente de deslumbramiento. En el caso de las ventanas, (L_s) es la luminancia del cielo (u otra superficie brillante) vista a través de la ventana (cuanto mayor es el brillo de la fuente o del cielo, mayor es el índice);
- El ángulo sólido delimitado por la fuente (ω_s). En el caso de las ventanas, (ω_s) es el tamaño aparente del área visible del cielo desde el ojo del observador (cuanto mayor es el área, mayor es el índice);
- El desplazamiento angular (Ψ) de la fuente desde la línea de visión del observador. En el caso de las ventanas, (Ψ) describe la posición del cielo visible dentro del campo de visión (cuanto mayor es la lejanía del centro de la visión, menor es el índice);
- La luminancia del campo general (L_b) que describe los niveles de adaptación del ojo del observador (también llamada la luminancia del fondo, del inglés, *background luminance*). En el caso de las ventanas, (L_b) es la luminancia media de la habitación excluyendo el cielo visible (cuanto mayor es la luminosidad de la habitación, menor es el índice).

En la búsqueda del mayor grado de fiabilidad de la fórmula, el tamaño de la fuente aparece como un factor crítico. Su influencia es tal que acaba provocando una escisión entre las fórmulas que evalúan la iluminación artificial (fuentes de pequeño tamaño) y las pretenden ser específicas para la evaluación de la iluminación natural (fuentes de gran tamaño). No obstante, esta es siempre una cuestión de continua discusión. A menudo, los trabajos de investigación juzgan que las fórmulas vinculadas con la iluminación natural no ofrecen una buena respuesta y que siguen siendo más propias para la evaluación de fuentes pequeñas (p.ej. BGI). Algunas fórmulas validadas para la evaluación de la iluminación artificial pretenden aplicarse también para la evaluación de la iluminación natural (p. ej. CGI). El motivo es la voluntad de estandarización de un único método de cálculo, así como posibilitar la evaluación de escenas iluminadas simultáneamente por la luz artificial y la natural, sin descartar en algunos casos la luz solar (p. ej. DGI_N).

El segundo elemento crítico es la definición de aquellas luminancias que son objeto de comparación con las luminancias correspondientes a las fuentes de deslumbramiento. Respecto a este aspecto, también hay divergencia de opiniones. Por una parte, ciertas formulas (p.ej. BGI, DGI y UGR) deciden establecer la comparación con la luminancia del fondo (Lb), excluyendo la fuente y haciendo énfasis en la evaluación del contraste entre las superficies más brillantes y las restantes superficies (fondo). Por otra parte, otras propuestas consideran que es más conveniente evaluar el efecto de superficies brillantes en relación a la adaptación del ojo frente a la visión del conjunto (p.ej. CGI, DGI_N y DGP). En este caso, la iluminancia vertical en la posición del observador (Ev), que incluye el efecto de las fuentes de deslumbramiento, describe la adaptación del ojo y pasa a ser un factor relevante que incluso motiva notables modificaciones en la formulación respecto a las propuestas primigenias de los índices de deslumbramiento.

Este capítulo dará cuenta de que la comparación entre los diferentes índices es a menudo difícil de argumentar puesto que su definición parte de condiciones experimentales que son notablemente distintas. Algunos índices (p.ej. BGI y DGI) son validados a través de miradas frontales dirigidas hacia una superficie brillante artificial que simula ser una ventana (hecho que suscita críticas cuando se pretenden validar estos índices para medir el efecto causado por las ventanas). Otros índices (p.ej. DGP) basan su definición en el estudio de casos reales en los que el observador no dirige la mirada hacia las superficies deslumbrantes sino que se fija sobre una superficie de trabajo vertical (la pantalla de ordenador) que ocupa el centro de la visión y que implica una mirada horizontal y cierta visión global del espacio.

Algunos dilemas acaban de ser explicados a través este resumen introductorio. Estos y otros son objeto de más comentarios en los siguientes capítulos. Cada uno de ellos ofrece una descripción y un análisis pormenorizado de cada uno de los índices más relevantes. A continuación se listan los ocho índices que forman parte del estudio:

- BRS Glare Equation (BRS o BGI)
- Cornell Equation o Daylight Glare Index (DGI)
- CIE Glare Index (CGI)
- Unified Glare Rating (UGR)
- Visual Comfort Probability (VCP)
- New Daylight Glare Index (DGI_N)
- Predicted Glare Sensation Vote (PGSV)
- Daylight Glare Probability (DGP)

Los subcapítulos dedicados a los índices DGI y DGP merecerán más comentarios y, por tanto, extensión. Estos dos índices serán los seleccionados para formar parte de la metodología que servirá para evaluar los casos de estudio. La elección de estos dos índices se debe a dos motivos. El primer motivo es el respaldo que han merecido a través de experimentos en los que se ponía a prueba su validez. El segundo motivo es que estas dos formulaciones están basadas en las dos diferentes aproximaciones que anteriormente han sido mencionadas. El uno (DGI) pone en relieve la luminancia del fondo (Lb) y, por tanto, basa el análisis en el contraste visual. El otro (DGP) enfatiza el efecto de la iluminancia vertical en la posición del observador (Ev) y, por tanto, la adaptación visual del observador al conjunto de la escena. Como bien es sabido esto dos índices parten de la evaluación del deslumbramiento definido como molesto pero no se descarta que los casos de estudio los pongan a prueba en condiciones más extremas, propias del deslumbramiento definido como perturbador, que puede ocasionar la presencia de la luz solar en las escenas. De hecho, la frontera entre un deslumbramiento molesto o perturbador no es siempre tan obvia de distinguir. Este es el motivo por el cual los resultados de algunas de las fórmulas aplicadas a la iluminación artificial sugieren, en ocasiones, estar próximos a la evaluación del deslumbramiento perturbador.

3.2. BRS glare equation (BRS o BGI)

La concreción de este método parte de los experimentos de Hopkinson y Bradley (1926, 1929). Dando continuidad a estos trabajos, en Inglaterra, en la Building Research Station (BRS), Hopkinson & Petherbridge (1950) desarrollan la ecuación BRS (o BGI). Su propuesta permite clasificar la sensación de deslumbramiento de acuerdo con los siguientes grados: *just noticeable* (apenas perceptible), *just aceptable* (apenas admisible), *just uncomfortable* (apenas molesto) y *just intolerable* (apenas intolerable). La ecuación empírica desarrollada tiene la siguiente forma:

$$BGI = 10log_{10}0.478\sum_{i=1}^{n}\frac{L_s^{1.6}\cdot\omega_s^{0.8}}{L_b\cdot P^{1.6}} \qquad (3\text{-}2)$$

Donde:

- P es el índice Guth de posición (Luckiesh & Guth, 1949) y expresa la variación de la sensación de deslumbramiento en función del azimut y de la elevación de la fuente respecto a la línea de visión del observador;
- n es el número de fuentes de deslumbramiento.

Las investigaciones realizadas por Hopkinson en solitario (1949, 1963), o formando equipo con Bradley (1960) y con Collins (1963), son las primeras que ponen a prueba la validez del BGI para evaluar el deslumbramiento que causan las fuentes extensas (techos luminosos o ventanas). Más tarde, otras investigaciones completan estos primeros trabajos y concluyen que el índice BGI es poco fiable para la evaluación de las fuentes extensas. Chauvel, Collins, Dogniaux y Longmore (1982) exponen que el BGI no predice el deslumbramiento de estas fuentes con exactitud y añade que no considera apropiadamente el efecto de la adaptación del ojo del observador. Iwata, Kimura, Shukuya, y Takano, (1990/91) comparan el BGI con el DGI y el CGI (véanse más adelante) y demuestran que el BGI es el menos exacto cuando se evalúa el deslumbramiento causado por las fuentes extensas. Ellos concluyen que el BGI fue originalmente previsto para fuentes puntuales pequeñas y no para fuentes grandes y extensas (ventanas). Osterhaus (1996) completa los trabajos anteriores y especifica que la aplicación del BGI debería limitarse a las fuentes con ángulos sólidos inferiores a 0.02 estereorradianes).

3.3. Cornell equation o Daylight Glare Index (DGI)

Las investigaciones citadas en el capítulo anterior demuestran que el índice BRS de deslumbramiento es aplicable para la iluminación artificial pero deja de serlo para la iluminación natural. La razón principal es el tamaño de la fuente de luz que, típicamente, excede un ángulo sólido de 0.02 estereorradianes. Cuando este ángulo sólido es superado, la posible fuente de deslumbramiento cubre una parte significativa del campo visual. Este hecho justifica un mayor nivel de adaptación del ojo, un menor efecto de contraste, y, en consecuencia, una disminución de la sensación de deslumbramiento. Las fuentes de luz eléctrica de tamaño reducido no provocan la misma reacción por parte del observador. Puesto que las fuentes no ocupan una porción considerable del campo visual. Esto explica que el nivel de adaptación del observador no dependa de la luminancia de estas fuentes. En la ecuación destinada a la valoración de un posible deslumbramiento causado por unas fuentes eléctricas pequeñas, el nivel de adaptación lo determinan las luminancias del fondo (Hopkinson & Bradley, 1960), sin incluir las luminancias de las fuentes deslumbrantes. Como veremos a continuación, la formulación vinculada a la luz natural no puede expresarse el mismo modo. La adaptación del observador debe considerar la luminancia de la ventana (la fuente de luz).

Hopkinson desarrolla el Daylight Glare Index (DGI) para proveer de un método adecuado para valorar el deslumbramiento molesto causado por las fuentes de luz naturales. También conocido como la “Cornell equation”, el índice DGI es una modificación del BGI adaptada para predecir el deslumbramiento de una fuente extensa (ventana). El nuevo índice es el resultado del trabajo conjunto entre el Building Research Establishment (BRE) y en la Cornell University (USA) (Hopkinson, 1972; Chauvel, *et al.*, 1982). En esta experimentación, unas lámparas fluorescentes, ubicadas detrás de una pantalla difusora opalina, recrean la presencia de una fuente extensa.

La formulación de la ecuación es la siguiente:

$$DGI = 10log_{10}0.48\sum_{i=1}^{n}\frac{L_S^{1.6}\cdot\Omega_S^{0.8}}{L_b+0.07\omega_S^{0.5}L_S} \tag{3-3}$$

Donde:

- Ω_s (sr) es el ángulo sólido delimitado por la fuente de deslumbramiento modificado por la posición de la fuente en relación al campo de visión (índice de posición Guth).

La escala de grados de sensación de deslumbramiento obtenidos con el Daylight Glare Index (DGI) está relacionada con la escala del British Glare Index (BGI) de Hopkinson. La relación puede expresarse en forma de ecuación (Fisekis, Davies, Kolokotroni, & Langford, 2003):

$$DGI = {}^{2}\!/_{3}\,(BGI + 14) \tag{3-4}$$

La siguiente tabla (LEARN, 2005) concreta la relación existente entre los grados de sensación del deslumbramiento y los valores de los índices. La tabla permite verificar el cumplimiento de la ecuación 3-4.

Tabla 3.1. Regiones de deslumbramiento y su índice correspondiente (BGI y DGI)

Zone	**Region**	**BGI**	**DGI**
Discomfort zone	intolerable	>28	>28
	just intolerable	28	28
	uncomfortable	25	26
	just uncomfortable	22	24
Comfort zone	acceptable	19	22
	just acceptable	16	20
	noticeable	13	18
	just perceptible	10	16

A principios de los años 70, Hopkinson publica unos trabajos de campo que evalúan los grados de deslumbramiento en salas de hospital y en aulas de colegios (Hopkinson, 1970/1971, 1972). Los resultados otorgan un respaldo razonable a la ecuación Cornell. Desde entonces, el uso de esta ecuación es aceptado para la predicción del deslumbramiento causado por la luz natural.

Las investigaciones dirigidas por Chauvel *et al*. (1982) completan el trabajo de Hopkinson. Los resultados obtenidos sirven para especificar que, frente a grados de deslumbramiento moderados, existe una mayor tolerancia por parte de los observadores que visualizan el cielo (a través de las ventanas reales) que por parte de aquellos que visualizan una fuente de luz artificial del mismo tamaño y de luminancia comparable. Esta mayor tolerancia deja de existir con grados de deslumbramiento elevados.

Además, Chauvel *et al.* (1982) añaden otra cuestión. Según sus investigaciones, el deslumbramiento molesto de una ventana es prácticamente independiente del tamaño de la ventana y de su distancia hasta el observador. Él afirma que el deslumbramiento depende críticamente de la luminancia de la porción de cielo vista a través de la ventana. Las aportaciones de Chauvel *et al.* motivan una ligera modificación de la ecuación Cornell que añade una variable para describir la luminancia media del cielo en el plano de la ventana (Robbins, 1986).

Iwata *et al.* (1990/91) validan las afirmaciones de Chauvel *et al.* (1982). Ellos también afirman que el deslumbramiento percibido por los observadores enfrentados a condiciones con cielos reales es menor que el predicho a través del cálculo con la ecuación DGI. Sin embargo, las diferencias de los procedimientos experimentales (tiempos de adaptación menores, si se establece la comparación con los estudios originales de Hopkinson) y las diferencias culturales entre los sujetos japoneses y los europeos o americanos (los japoneses demostraron ser más tolerantes al deslumbramiento) podrían haber contribuido a estos descubrimientos. Además, Iwata *et al.* añaden una comparación entre los diferentes índices existentes en el momento. Sus resultados demuestran que, utilizando una fuente de deslumbramiento artificial de gran extensión, existe una mayor correlación, entre la fórmula Cornell y los votos de deslumbramiento, que, entre el índice BGI o el CGI (véase más adelante) y los mismos votos.

Boubekri y Boyer (1992) publican otro estudio de validación de la ecuación Cornell. Con su trabajo demuestran, una vez más, que la correlación entre el deslumbramiento de las ventanas reales y la predicción del deslumbramiento no es tan fuerte como cuando se evalúan las fuentes de luz artificial extensas. Sus resultados ponen de manifiesto que existe una tolerancia de unos ligeros grados más (no concretan cuantos) cuando se evalúa el deslumbramiento de una ventana, en comparación con la situación de una fuente iluminación artificial del mismo tamaño. En cambio, la experimentación motiva su especulación sobre la causa que motiva la mayor tolerancia. Según ellos, las vistas agradables condicionan favorablemente (sensación de deslumbramiento menor) a los observadores.

Todos los estudios citados (Chauvel *et al.,* 1982; Iwata *et al*., 1990/91; Boubekri y Boyer, 1992) comparten una misma afirmación. Sin ahondar en las justificaciones, todos ellos mencionan que el DGI es menos fiable cuando la ventana es paralela a la dirección de la visión del observador.

Además, otros estudios detectan nuevas dificultades de fiabilidad de los resultados del DGI ante ciertas casuísticas específicas. Waters, Mistrick y Bernecker (1995) sugieren que las fuentes de deslumbramiento no uniformes (ventanas con vistas de superficies con diferentes luminancias) no están consideradas en el DGI ya que este índice fue desarrollado a través de los datos obtenidos con fuentes de luz uniformes. Con la voluntad de esclarecer unas dudas similares, otras investigaciones (CIE, 1983; Iwata & Tokura, 1998) documentan que las diferentes subdivisiones de una fuente de deslumbramiento uniforme provocan la obtención de diferentes resultados del índice de deslumbramiento (aunque la fuente es vista como una única fuente por el observador). Además de afectar al DGI, este mismo problema afecta también a otros índices (BGI y VCP), y es debido a los exponentes de cada parámetro de las diferentes fórmulas de predicción del deslumbramiento molesto. Einhort (CIE, 1983) plantea que matemáticamente es esencial que, para la adición y subdivisión las fuentes de deslumbramiento, el exponente del ángulo sólido de las fuentes de deslumbramiento sea igual a 1. Este descubrimiento es incorporado en el índice CIE de deslumbramiento y en el sistema UGR (véase más adelante).

Como alternativa a las discusiones vinculadas estrictamente con el desarrollo de la formulación, otras investigaciones atienden a las casuísticas de diseño que justifican la aplicación de los índices de deslumbramiento (Gall, Vandahl, Jordanow, & Jordanowa, 2000). Estos trabajos evalúan la idoneidad de diferentes sistemas de protección para prevenir el deslumbramiento presente sobre las pantallas de ordenador. Además de este trabajo basado en cuestionarios, los mismos investigadores realizan unas mediciones gracias a una cámara de luminancias que permite calcular más precisamente el índice DGI. Sus resultados demuestran una buena correlación (r=0.91) del DGI cuando evalúan el efecto causado por una ventana artificial (en combinación con los diferentes sistemas de protección del deslumbramiento). Cuando evalúan la sensación frente a una ventana real, sus resultados manifiestan una correlación más débil (r=0.53). El DGI sobrevalora la situación, es decir, que el observador tolera más deslumbramiento del que predice el DGI.

Todas las observaciones anteriores sugieren que los resultados del índice DGI de deslumbramiento para la luz natural presentan límites de fiabilidad. Pero, a pesar de sus limitaciones y ante la falta de alternativas validadas, el DGI sigue siendo el indicador más comúnmente utilizado para aplicaciones relacionadas con la luz natural, (Wilks & Osterhaus, 2003; Velds 2001). Posiblemente, su discutible fiabilidad explica que los únicos usuarios de este índice sean los investigadores y los consultores especializados en iluminación. A diferencia del sistema UGR (véase más adelante) que, al poco tiempo de su definición, se convirtió en un estándar para las aplicaciones propias de la iluminación eléctrica (muchos países adoptaron este método), el DGI no consigue imponerse en la práctica profesional ya que no aporta garantías de fiabilidad ante la valoración del deslumbramiento molesto causado por la luz natural.

3.4. CIE glare index (CGI)

El CGI es un índice desarrollado por un comité de la Comissión Internationale de l'Éclairage (CIE, 1983) liderado por Einhorn (1969, 1979). El índice propone corregir la inconsistencia matemática de la ecuación BRS cuando evalúa la presencia de múltiples fuentes de deslumbramiento. El índice CGI es esencialmente una manipulación matemática y un intento de combinar los mejores puntos de los principales sistemas de evaluación existentes en aquel momento. Desafortunadamente, no se realizaron nuevos experimentos para ganar un entendimiento adicional o para poner a prueba la validez de las modificaciones propuestas. Inicialmente, el CGI se desarrolla para describir el deslumbramiento causado por las fuentes de luz artificial. Aunque, más adelante, el CIE adopta la ecuación propuesta por Einhorn como un método unificado de valoración del deslumbramiento:

$$CGI = 8log_{10}2 \cdot \frac{\left[1+\frac{E_d}{500}\right]}{E_d+E_i} \cdot \sum_{i=1}^{n} \frac{L_s^2 \omega_s}{P^2} \tag{3-5}$$

Donde:

- E_d (lux) es la iluminancia directa vertical sobre el ojo debida a todas las fuentes;
- E_i (lux) es la iluminancia indirecta sobre el ojo ($E_i = \pi L_b$)

Esta fórmula está esencialmente dividida en dos partes, una describiendo el ambiente luminoso de la habitación y la otra describiendo el efecto combinado de la luminancia, el tamaño y la posición de la fuente de deslumbramiento. El índice CGI, comparado con los índices anteriores, incluye la contribución de la fuente de deslumbramiento en la adaptación del observador. Es por ello que la descripción del ambiente luminoso de la habitación se expresa a través de la iluminancia vertical en el ojo. Esta es una ventaja cuando se evalúan fuentes de deslumbramiento de gran superficie que son cercanas o adyacentes a la tarea visual. Bajo estas condiciones, puede ser esperado que una fuente de deslumbramiento extensiva contribuya significativamente en la adaptación del observador como si fuera una parte esencial del amplio fondo frente al cual el observador vería la tarea de la misma manera que la fuente de deslumbramiento. Pese al acertado planteamiento de este índice, pocos países han adoptado oficialmente esta aproximación en sus estándares.

3.5. CIE Unified Glare Rating system (UGR)

Desde su aparición, los métodos de predicción del deslumbramiento han sido sujeto de crecientes críticas, dadas sus debilidades y limitaciones. Para remediarlo, la comisión CIE se propone desarrollar un sistema de predicción del deslumbramiento nuevo, que conserve las ventajas de los sistemas previos y elimine sus debilidades, que sea “ultra simple” y, finalmente, que interese a la mayoría de los países (Sørensen, 1987). Dentro de la División 3, La CIE establece el nuevo comité técnico *TC 3-13: Discomfort Glare Evaluation Systems* con Sørensen es el presidente. Su premisa es encontrar una nueva fórmula “de compromiso”, es decir, una propuesta que presente compatibilidades con los sistemas CGI y BGI.

Sørensen simplifica el sistema CGI para proponer el Unified Glare Rating (UGR). La comisión CIE valida la nueva propuesta a través de su publicación “Dicomfort Glare in Interior Lighting” (CIE, 1995). El sistema UGR conserva, del índice CGI, la parte de la fórmula que describe el efecto combinado de la luminancia, el tamaño y la localización de las fuentes de deslumbramiento. Sin embargo, la descripción del ambiente luminoso de la habitación cambia y, de nuevo, se reduce a la luminancia del fondo sin incluir a las fuentes de deslumbramiento. La contribución de la fuente de deslumbramiento a la adaptación del observador (la iluminancia directa en el ojo) vuelve a ser omitida. El documento argumenta que, en la práctica, el efecto de las fuentes es muy pequeño cuando la fórmula se aplica a interiores cuyas iluminancias se encuentran dentro de los rangos recomendados para los espacios de trabajo. La experiencia sugiere que esta suposición es aceptable para la luz eléctrica. En cambio, la misma suposición deja de ser acertada cuando la luz natural juega un papel importante en los interiores.

En definitiva, el “Unified Gare Rating System” (UGR) logra combinar ciertos aspectos de los índices CGI y BGI, y, centra la evaluación en los sistemas de iluminación artificial (fuentes con un ángulo sólido de 3.10^{-4} a 10^{-1} sr).

La ecuación que caracteriza el sistema es:

$$UGR = 8log_{10}\frac{0.25}{L_b}\cdot\sum_{i=1}^{n}\frac{L_S^2\omega_S}{P^2} \quad (3\text{-}6)$$

Puesto que procura un procedimiento de cálculo más sencillo, el sistema UGR gana un reconocimiento más amplio, incluyendo su aplicación en los EEUU, dónde es revisado para remplazar el sistema Visual Comfort Probability. En la mayoría de los casos, los índices de deslumbramiento calculados con el sistema UGR no se desvían más de una unidad respecto a la tradicional escala de Hopkinson del sistema BGI. Los valores prácticos del UGR adoptan, a partir del BGI, un rango entre 10 (no discomfort glare) y 30 (significant discomfort glare). La fórmula UGR será considerada como una aportación que incluye las mejores partes de los sistemas previos, en términos de exactitud matemática y de facilidad de uso. En relación a los trabajos experimentales previos, la fórmula UGR también incorpora el índice Guth de posición (para evaluar el impacto de la posición de la fuente). La comisión CIE completa su trabajo ofreciendo una serie de curvas y tablas basadas en la fórmula del índice UGR y proponiendo sus sugerencias para un método práctico de evaluación del deslumbramiento molesto (CIE, 1995).

Como ya se ha indicado, la aplicación del sistema UGR en su forma original está limitada a fuentes con ángulos sólidos entre $3x10^{-4}$ y $1x10^{-1}$ estereorradianes. Los trabajos de investigación demuestran que estos ángulos sólidos equivalen a áreas proyectadas de entre 0,005 m^2 y 1,5 m^2. Los mismos trabajos demuestran que las fuentes más pequeñas serán penalizadas por la fórmula, dando lugar a clasificaciones de deslumbramiento demasiado elevadas. En cambio, las fuentes más grandes serán tratadas demasiado indulgentemente. También ha sido apuntado que la fórmula no sería precisa para evaluar fuentes luminosas complejas.

Para superar las limitaciones del sistema UGR, la comisión CIE (2002) propone unas recomendaciones suplementarias. Desafortunadamente, el líder del comité técnico que prepara estas recomendaciones suplementarias, Einhorn, fallece antes de que el documento sea ensamblado. Según los restantes miembros del comité, Einhorn es incapaz de comunicar, antes de su fallecimiento, todos los detalles de su trabajo y, menos aún, los fundamentos que justificaban sus modificaciones matemáticas.

Para fuentes muy pequeñas (tamaño inferior a 0,005 m^2), las recomendaciones suplementarias se basan en las investigaciones anteriores (Benz, 1966; Paul, 1997). Estos dos investigadores sugieren que la intensidad de la fuente y el área proyectada son determinantes en la sensación de deslumbramiento. Para estos casos, la publicación CIE (2002) proporciona una versión modificada de la ecuación UGR original.

Para fuentes mayores a 1.5 m^2, pero excluyendo específicamente los techos luminosos y las iluminaciones indirectas extensivas, el mismo documento recomienda una modificación bastante sustancial a la ecuación UGR original. Sin embargo, no se explica cómo fue deducida esta ecuación, ni tampoco se referencia ninguna investigación de soporte.

Para los techos luminosos y los sistemas de iluminación indirecta uniforme, las recomendaciones sugieren que una única fórmula no expresa con exactitud la sensación de deslumbramiento de los cielos luminosos y que una extensión de la fórmula UGR sería demasiado tolerante y permitiría un deslumbramiento inaceptable (CIE, 2002).

En cambio, con intención de evitar los difíciles cálculos contemplando las múltiples casuísticas, el documento proporciona una tabla sencilla de iluminancias medias con las correspondientes clasificaciones de deslumbramiento. El documento no especifica dónde se mide la iluminancia, pero es presumible que sea sobre la altura de un plano de trabajo. El texto tampoco proporciona ninguna información que justifique cómo fueron establecidas las correspondientes clasificaciones de la sensación de deslumbramiento.

Para iluminaciones indirectas no uniformes, el documento CIE propone un término que no se define más allá, una ecuación que propone establecer la iluminancia media límite en una habitación (presumiblemente sobre el plano de trabajo). Es interesante indicar que, según el documento, cuando crece la luminancia media de los puntos luminosos, decrece la correspondiente iluminancia media de la habitación (Eble-Hawkins & Waters, 2003). Este resultado parece ir en contra de la intuición. Normalmente, lo esperado sería que el número de luminarias indirectas o la luminancia efectiva que proporcionan al techo plano deberían ser reducidas para conseguir una menor iluminancia sobre la altura del plano de trabajo. Sin embargo, el documento no referencia ninguna investigación explicando la lógica de esta afirmación que, probablemente, debería ser tratada con precaución.

Para fuentes complejas, el documento CIE diferencia entre fuentes difusoras y especulares. El documento propone dos formulaciones distintas para calcular la clase de deslumbramiento de este tipo de fuentes complejas. Concretamente, para las luminarias semicirculares, el documento recomienda calcular la valoración del deslumbramiento a través de las dos ecuaciones y promediar el resultado. De nuevo no aparecen referenciadas investigaciones que avalen la validez de estas ecuaciones (Eble-Hawkins & Waters, 2003). Aunque las modificaciones podrían basarse en equilibrios conocidos, la ausencia de explicaciones a causa del fallecimiento de Einhorn dificulta su evaluación crítica.

Finalmente, pese a que las recomendaciones suplementarias de Einhorn pretenden subsanar las limitaciones de sistema UGR frente a las fuentes grandes y complejas (ventanas), ningún trabajo experimental permite validar la aportación de estas recomendaciones.

3.6. Visual Comfort Probability (VCP)

El método “Visual Comfort Probability” deriva de los trabajos de Luckiesh junto con Hollyday (1925) y junto con Guth (1949). El método VCP (IES, 1993) proporciona una clasificación del confort visual en términos de porcentaje de personas que consideran aceptable un determinado sistema de iluminación artificial (CIE, 1983). En principio, el método es aplicable para cualquier tipo de sistema de iluminación artificial.

El método VCP exige, primero, el cálculo del “Discomfort Glare Rating” (DGR), el cual se expresa, matemáticamente, como:

$$DGR = \left(\sum_{i=1}^{n} M_i\right)^{n^{-0.0914}} \tag{3-7}$$

Donde:

$$M = \left(\frac{0.5 \cdot L_S(20.4\omega_S + 1.52\omega_S + 0.075)}{P \cdot F_v^{0.44}}\right) \tag{3-8}$$

$$F_v = \left(\frac{L_W\omega_W + L_f\omega_f + L_C\omega_C + L_S\omega_S}{5}\right) \tag{3-9}$$

Donde:

- M es el índice de sensación para la fuente deslumbrante;
- F_v (cd/m^2) es la luminancia media de la totalidad del campo visual;
- L (cd/m^2) es la luminancia media de las paredes (L_w), el suelo (L_f), el techo (L_c), y la fuente (L_s);
- ω (sr) es el ángulo sólido (delimitado desde el ojo del observador) de las paredes (ω_w), el suelo (ω_f), el techo (ω_c) y la fuente (ω_s).

Una vez realizado el cálculo del DGR, es posible calcular el indicador VCP. La ecuación que describe el cálculo es la siguiente:

$$VCP = 279 - 110(log_{10}DGR) \tag{3-10}$$

Esta ecuación es una aproximación válida para un rango de resultados del indicador VCP comprendido entre 20 y 85, (respectivamente, DGR de 55 hasta 200). Si se supera este rango, la siguiente corrección de la fórmula debe ser aplicada:

$$VCP = 279 - 110(log_{10}DGR) + 350(log_{10}DGR - 2.08)^5 \tag{3-11}$$

Finalmente, ciertos trabajos (IES, 1993) afirman que VCP no puede ser aplicado para las fuentes de deslumbramiento demasiado pequeñas, demasiado grandes o que carezcan de uniformidad.

3.7. New daylight glare index DGI_N

Nazzal (2001) propone un nuevo índice de deslumbramiento (DGI_N). Este nuevo índice propone dar continuidad al índice DGI existente. Su expresión matemática introduce matices que sirven para afinar el cálculo.

La ecuación vinculada al DGI_N es la siguiente:

$$DGI_N = 8log_{10}0.25\left[\frac{\sum_{i=1}^{n} L_{ext}^2 \Omega_{pN}}{L_{adapt}+0.07\left(\sum_{i=1}^{n} L_{window}^2 \omega_N\right)^{0.5}}\right] \quad (3\text{-}12)$$

Donde:

- L_{ext} (cd/m^2) es la luminancia desprotegida vertical media del exterior;
- L_{window} (cd/m^2) es la luminancia protegida vertical media de la ventana;
- L_{adapt} (cd/m^2) es la luminancia desprotegida vertical media de los alrededores;
- ω_n (sr) es ángulo sólido delimitado por la fuente de deslumbramiento (ventana) hasta el punto de observación
- Ω_{pN} es el factor de posición que depende de la geometría de la ventana y de la distancia desde el lugar de observación hasta el centro del área de la ventana.

Este índice propone algunas mejoras para la valoración cuantitativa de la sensación de deslumbramiento causada por la luz natural y por la radiación solar directa. Pero ningún estudio de comprobación (que reconozca las respuestas de los usuarios frente a las diferentes condiciones de estudio) acompaña al cálculo teórico. Así, la propuesta carece de un respaldo práctico que sirva para validarla (Osterhaus, 2001). Además, el cálculo del DGI_N supone una dificultad añadida. El cálculo requiere cierta información geométrica que, habitualmente, no está disponible; especialmente, si se trabaja con las imágenes obtenidas a través del uso de cámaras de luminancias.

3.8. Predicted glare sensation vote (PGSV)

El PGSV es una fórmula basada en la realización de experimentos con ventanas simuladas. Esta simulación de las ventanas se realiza a través del uso de la iluminación artificial, con fuentes luminosas uniformes (Tokura, Iwata, Shukuya, & Kimura, 1993; Tokura, Iwata, & Shukuya, 1996). Estas condiciones facilitan la evaluación puesto que la luminancia de las fuentes es regulable. Pero, pone en duda la validez de los resultados, puesto que las ventanas reales son más complejas. A través de la ventana, múltiples luminancias pueden ser visualizadas (no una luminancia uniforme). Además, la visión del exterior contiene información que, si es agradable (un paisaje natural), implica una mayor tolerancia frente al deslumbramiento.

El PGSV se expresa como sigue:

$$PGSV = 3.2log_{10}L_{wp} - 0.64log_{10}\omega_s + (0.79log_{10}\omega_s - 0.61)log_{10}L_b - 8.2 \quad (3\text{-}13)$$

$$L_b = \left[\frac{\frac{E_v}{\pi} - L_{wp} \cdot \Phi_w}{1 - \Phi_w}\right] \quad (3\text{-}14)$$

Donde:

- E_v (lux) es la iluminancia vertical sobre el ojo;
- L_{wp} (cd/m2) es la luminancia visible dentro del plano de la ventana;
- Φ_w es el factor de configuración de la ventana.

Como puede apreciarse en la fórmula, el PGSV no incluye el índice de posición y, por lo tanto, solo apunta a la valoración del deslumbramiento de las ventanas localizadas en la línea de visión (Velds, 1999). Esta situación es extremadamente restrictiva.

3.9. Daylight glare probability (DGP)

Conceptualmente, el DGP no es comparable con los índices anteriores. El DGP expresa la probabilidad de que una persona sufra la molestia asociada al deslumbramiento. Este indicador no pretende cuantificar la magnitud de la molestia.

La definición del DGP (Wienold & Christoffersen, 2006) procede de las pruebas de laboratorio realizadas conjuntamente por el Fraunhofer Institute of Solar Energy Systems y por el Danish Building Research Institute. Los dos institutos establecen las mismas condiciones de estudio. En cada una de las dos ubicaciones, las pruebas ocupan dos locales experimentales idénticos: uno con los sujetos ("test room") y el otro con los equipos de medición. Además, las fachadas admiten tres configuraciones del tamaño de la parte acristalada. La "configuración pequeña" corresponde a un hueco de ventana en posición central. La "configuración media" equivale a una "fenêtre en longueur". La "configuración grande" es un muro cortina. Tres sistemas de control de la radiación se superponen a cada una de las tres configuraciones. El primero es una persiana veneciana de lamas convexas blancas. El segundo es una persiana veneciana de lamas cóncavas (de acabado especular). El tercero es una protección de lamas verticales de tejido transparente. A diferencia de otros estudios, en este caso, los sujetos no someten su mirada hacia la fuente de deslumbramiento. Durante el experimento, desarrollan una tarea de oficina con ordenador. En primer lugar se les posiciona en paralelo a la ventana y, después, en diagonal. La duración de la sesión completa es de 1h 45 min. Durante la mayor parte del tiempo, la posición de las persianas permite el acceso de la luz pero evita la presencia de la radiación directa en el interior. Los usuarios juzgan sus sensaciones a través de sus respuestas a un cuestionario.

Las mediciones realizadas simultáneamente sirven para el cálculo de dos de los índices de deslumbramiento (DGI y CGI). Estos dos índices son los que más se utilizan cuando la luz natural es objeto de estudio. Los autores de la investigación proponen una nueva herramienta informática, el software Evalglare, para gestionar las imágenes obtenidas con cámaras CCD. Evalglare permite la evaluación sistemática de los índices de deslumbramiento asociados a cada imagen. Para lograrlo, el Evalglare utiliza unos algoritmos para detectar automáticamente las áreas de la imagen (ventanas o superficies de radiación directa reflejada) que pueden causar un deslumbramiento.

Una selección de 349 casos permite la comparación entre los índices DGI y CGI calculados y la clasificación del deslumbramiento manifestada por los sujetos en los cuestionarios. El estudio demuestra que las diferencias individuales en la percepción del deslumbramiento provocan una gran dispersión de los resultados. La comparación demuestra la inexistencia de cualquier correlación aceptable. Para superar esta dificultad se introduce el concepto de probabilidad de que una persona perciba cierta molestia. Todos los sujetos cuya respuesta al cuestionario es “disturbing”, o “intolerable”, pasan a formar parte de la categoría de los perciben una molestia. Así, la probabilidad de molestia es comparada con los índices DGI y CGI calculados. La correlación matemática obtenida sigue siendo baja, pone en crisis la validez de estos índices DGI y CGI y justifica la propuesta de una nueva ecuación.

La nueva aproximación introduce el ya comentado concepto de probabilidad de que una persona perciba molestia. La función DGPs (Simplified Daylight Glare Probability) permite un cálculo simplificado de dicha probabilidad de molestia. En esta ecuación, la iluminancia vertical en la posición de los ojos del observador pasa a ser fundamental.

$$DGPs = 6.22 \times 10^{-5} \times E_v + 0.184 \tag{3-15}$$

El motivo de la introducción de la iluminancia vertical es que demuestra una alta correlación con la probabilidad de molestia. La ventaja de esta fórmula es su extrema simplicidad que permite acelerar los cálculos de evaluación. El problema es que no considera las fuentes de deslumbramiento. Su autor (Wienold, 2007) advierte que este índice sólo puede ser aplicado si no hay presencia de luz solar directa o de reflexiones especulares en dirección del observador. Cuando se den estas circunstancias es necesaria la aplicación de un índice DGP mejorado que considera las fuentes de deslumbramiento y su posición dentro del campo visual. La mejora del DGP combina la iluminancia vertical, el sumatorio asociado a la fuente de deslumbramiento y algunos coeficientes obtenidos a través de algoritmos de optimización aleatorios. La fórmula DGP detallada es la siguiente:

$$DGP = 5.87 \times 10^{-5} E_V + 9.18 \times 10^{-2} log_{10}\left(1 + \sum_i \frac{L_{s,i}^2 w_{s,i}}{E_V^{1.87} P_i^2}\right) + 0.16$$

(3-16)

Donde:

- E_v (lux) es la iluminancia vertical sobre el ojo;
- L_s (cd/m2) es la luminancia de la fuente luminosa;
- ω_s (sr) es el ángulo sólido de la fuente luminosa;
- P es el índice de posición de la fuente luminosa.

La luminancia del fondo (L_b) como medida del nivel de adaptación de la visión queda descartada ya que la fuentes de deslumbramiento extensivas (ventanas) tienen un impacto notable sobre el nivel de adaptación. En su lugar, los autores proponen la E_v como un valor del nivel de adaptación.

La evaluación de los resultados de los experimentos muestra una buena correlación entre el DGP y las respuestas de los sujetos. Los autores califican el DGP como una herramienta fiable para las situaciones de oficina ya que el modelo está validado por los 349 casos diferentes correspondientes a 75 sujetos diferentes en dos países. Aunque, la nueva ecuación debería ser confirmada por investigaciones adicionales. Su modelo de probabilidad debería ser puesto a prueba con otros elementos de control de la radiación y frente a escenas lumínicas diversas, poniendo más énfasis en escenas que no sean tan luminosas como las de las condiciones experimentales. No obstante, ciertos parámetros adicionales, como por ejemplo la calidad de la vista exterior, deberían ser considerados para validar la aplicación de la ecuación en el caso de los edificios de oficinas comunes.

Más allá del DGP, los autores de esta investigación manifiestan el potencial de los mapas de luminancias obtenidos a través de cámaras CCD y proponen el uso de un nuevo software propio (Evalglare) como herramienta para la gestión de la imagen y la detección de las posibles fuentes de deslumbramiento.

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Chapter 4: Research methodology

4.1. Radiance, Webhdrtools, Evalglare

The previous chapter defines the metrics which are employed to determine whether a visual field will cause glare or not. Nonetheless, to apply those metrics, it is previously necessary to measure the luminances and the size and position of each spot of the visual field. The current chapter explains how this is possible thanks to some specific techniques of photography and the precise software. If we want to create an image equivalent to a human visual field, two main issues need to be solved.

Firstly, the lens of the camera needs to raise the human angles of vision. Nowadays, the photographic industry offers several fisheye lenses which permit to capture horizontal and vertical angles of 180 degrees and create an image with a particular geometric projection. The Sigma 4.5mm fisheye lens was used to assess the case studies, both in London and Barcelona. This fisheye lens creates images using an *equisolid angle projection*. This projection type is useful because the resulting picture maintains the proportion between the solid angles of the visual field, which need to be measured. Secondly, the sensor of the camera should capture a high range of luminances. After a certain time of adaptation, the human eye can read the information contained in very dark spots (0,000.000.1 cd/m²) and in very bright ones (1.000.000 cd/m²). Once adapted, the eye can cope with a luminance range of 1:1000, but for a part of the scene, this can be as high as 1:10.000 (Jaloxa, 2011a). However, this range is too high for the sensor's sensitivity of a common camera. The photographic technique called High Dynamic Range (HDR) appears to surpass the common limits. Often the settings of a contemporary camera make possible to produce an HDR image automatically. Another option is to take the same picture with different exposures and afterwards combine them to create an HDR image. The bracketing settings of a camera are useful for this purpose. The camera Nikon D200 (used for the assessments in London) makes possible to shoot nine consecutive exposures pressing the shooter just once. On the other hand, three exposures are the maximum permitted by the bracketing option of the Nikon D70 (assessments in Barcelona). The solution to produce nine exposures is to repeat the procedure three times while the centre of the three exposures is shifted.

Once the work with the camera is done, it is time to process the nine images to create a single HDR image by means of *hdrgen*, which is a Radiance tool created by G. Ward (1998a, 1998b, 2006). This image describes the scene and permits to convert the information of each pixel in a value of brightness, measured in cd/m2. Afterwards, a false coloured image represents the brightness of each pixel a single luminance map. Axel Jacobs created the Webhdrtools (Jaloxa, 2013) to make easier all the procedures and to offer multiple options of calibration to improve the accuracy of the results.

Finally, having obtained the brightness (or luminance) of each pixel, it is possible to apply the metrics of glare. *Findglare* is another Radiance tool (Mcneil, 2013) which processes the information in order to calculate multiple glare indexes. Again, Greg Ward was responsible of the development of that tool. Evalglare is a different tool that is useful to do the same work and to compare the results with those of *Findglare*. In addition, it facilitates the calculation of the DGP (Daylight Glare Probability) index and generates a very useful image with all the pixels which are susceptible to provoke glare grouped in patches depicted with the same colour. Evalglare was created by Jan Wienold (2004, 2006, 2009a, 2009b and 2010) and has motivated many works to test its accuracy.

In order to automatize the procedures, a script was written in bash. Axel Jacobs and the author of the thesis worked together to make possible this new script that permits the simultaneous work of Radiance, Webhdrtools and Evalglare. The next subchapters contain information which is useful for a better comprehension of the tools and validate the appropriate settings to do the assessments under sunlight conditions.

4.1.1. Development of a new script

The new script is called “fisheye-glare”. It is written in bash and runs in Linux OS. Its function is to process the photographs taken with a fisheye lens (of the same visual field with different exposures) in order to produce the information needed to assess the risk of glare. It runs a sequence of instructions (Radiance, Webhdrtools and Evalglare) and specifies some variables and options that are useful for the particularities of the case studies. This chapter presents the script (figures: 4-1, 4-2, 4-3 and 4-4) and explains its content as a sequence of steps. The highlights of the script are explained below following the order of the instructions. Radiance, Webhdrtools, Evalglare and ImageMagick are the programs which are run by the script. Most of the following details describe the information contained in the “man pages” defining the tools and the options.

First: Definition of the variables (figure 4-1)

The script determines the names of the working files and allows inserting manually the calibration factor known after a handful of good assessments.

Second: Read and create directories (figure 4-1)

The script descends into the directories given on the command line. Within each directory, the HDR images are composed and the glare calculations are carried out.

Third: Crop all photographs (figure 4-2)

The original images are cropped in a square containing the circular image, leaving four small black corners. The *crop* tool of ImageMagick is useful to do this task.

Fourth: Fix the EXIF header (figure 4-2)

The script runs the program *webhdr_jpgfixexif*. In order to determine the exposure value of an image, the program fixes the EXIF information (values 'ISO', 'F Number', and 'Exposure Time') that is embedded within a digital photograph.

D:\Desktop\fisheye_glare_v2a.bash lunes, 09 de septiembre de 2013 13:04

```
#!/bin/bash

# fisheye_glare.bash
# Descend into given directories and do some fun HDR stuff
#
# Author:  Axel Jacobs, Alexis Aguilar
# Date:    14 Jun 2013
# Version: 0.1.4

CF=1.3   # Adjust this for you camera!
SMALL_DIM=800
SPECIAL=0
# Tab-sep text file with all glare indices
GLARE="glare.tsv"
RERUN=0
AVRG="average.rsp"

# Output a header
echo -e "directory\tDGI_findglare\tEind_findglare\tDGI_evalglare\tDGP\tEv_evalglare" >> $GLARE
# Create this directory unless it already exists
if [ ! -d all_rsp ]; then
    mkdir all_rsp
fi

# Function to run on command line error, or when called with -h switch
usage()
{
cat << EOF
Usage: $0 options

This script decents into the directories given on the command line.
In each directory, an HDR image is composed, and glare calcs carried out.

OPTIONS:
   -h      Show this message
   -r      Re-run with an averaged RSP file.
   -s      Do something special
EOF
}

# Parse command line arguments (not really used yet...)
while getopts “hsr” OPTION; do
    case $OPTION in
        h)
            usage
            exit
            ;;
        s)
            SPECIAL=1
            ;;
        r)
            RERUN=1
            ;;
    esac
done
# Below is the only line you don't need to understand.
# It has to do with the getopts parser.
```

-1-

figure 4-1: Script “fisheye-glare” (page 1)

Fifth: Produce a heat map (figure 4-2)

The script runs the program *webhdr_jpgheatmap*. This program produces an image from an exposure-bracketed JPG sequence indicating the pixels from which reliable photometric HDR information cannot be derived. The option *–o* composes an output file (by default “heatmap.png”) which the software writes to the working directory.

Sixth: Run hdrgen (figure 4-2 and 4-3)

Hdrgen creates a high dynamic-range image from multiple exposures of a static scene. This software was written by Greg Ward. In this script, the input files may be JPEG (24-bit RGB trichromatic image) and the output is a Radiance HDR picture. Some options of the software are used in the script. Below, the information of the man pages which is useful in this script.

-f: toggle the lens flare removal. Normally ‘off’, this option is designed to reduce the scattered light from a camera's lens and aperture, which results in a slightly fogged appearance in high dynamic-range images.

-o (out_file): write a high dynamic-range image to the given file. If the file has a ‘.tif’ suffix, it will be written out as a LogLuv TIFF image. If it has a ‘.exr’ suffix, it will be written out as an ILM OpenEXR image. If it has any other suffix or none at all, it will be written out as an RLE RGBE Radiance picture.

-r (cam.rsp): use the given file for the camera's response curves. If this file exists, it must contain the coefficients of three polynomials, one for each colour primary. If the file does not exist, hdrgen will use its principal algorithm to derive these coefficients and write them out to this file for later use. If a scene contains no low frequency content or gradations of intensity, it may be impossible to derive the response curve from the exposure sequence. Thus, it is better to create this information once for a given camera and reuse it for other sequences.

D:\Desktop\fisheye_glare_v2a.bash lunes, 09 de septiembre de 2013 13:04

```
shift $(( ${OPTIND} - 1 ));

# Have we been given at least one directory to process?
if [ $# -eq 0 ]; then
    echo "Error: Need at least one directory." >&2
    usage
else
    echo "Directories ($#): $@"
fi

# Do all the directories exist?
for d in $@; do
    if [ ! -d $d ]; then
        echo "Error: Can't find directory $d" >&2
    fi
done

# Loop over all directories given on the command line
for d in $@; do
    echo "Descending into directory $d..."
    cd $d

    # Define some file names
    hdr="${d}.hdr"
    small="${d}_small.hdr"

    # Create the 'cropped' directory unless it already exists
    if [ ! -d cropped ]; then
        mkdir cropped
    fi

    # Crop all photographs to the size of the actual circular image
    for f in DSC_*.JPG; do
        echo "  Cropping and fixing $f..."
        # Check dimensions and offset!
        convert -crop 1564x1564+650+200 -quality 100 $f cropped/$f
        # Fix the EXIF header
        webhdr_jpgfixexif.pl cropped/$f
    done

    # Produce a heat map
    webhdr_jpgheatmap.pl -o ${d}_heatmap.png cropped/*.JPG

    # You should use an averaged RSP from a handfull of good RSPs.
    # Pay attention to white balance!
    # Run hdrgen
    if [ $RERUN -eq 0 ];then
        hdrgen -f -o tmp.hdr -r $d.rsp -a cropped/*.JPG
        if [ -f $d.rsp ]; then
            # To help you with an averaged RSP, we'll copy all RSP to a common directory...
            cp $d.rsp ../all_rsp/
            # Always visually inspect RSP and heatmap!
            webhdr_rspplot.pl --title "Directory $d" --output ${d}_rsp.png $d.rsp
            cp ${d}_rsp.png ../all_rsp/
        else
            # hdrgen failed and no RSP is created. This is bad.
            # Proceed with the next directory.
```

-2-

figure 4-2: Script “fisheye-glare”(page 2)

-a: toggle automatic exposure alignment. The default value is ‘on’, so giving this option one time switches it ‘off’. The alignment algorithm examines neighbouring exposures and finds the pixel offset in x and y that minimizes the difference in the two images. It may be necessary to switch this option ‘off’ when dealing with very dark or very bright exposures taken in a tripod-stabilized sequence.

webhdr_rspplot plots the *hdrgen response curve* to a PNG image. It reads one or more RSP files containing the response curve coefficients for/from processing an exposure-bracketed sequence of photographs into an HDR image. Those coefficients define a polynomial which *rspplot* plots to a PNG image with the help of *gnuplot*. The option --*title* gives a title of the graph. If not given, not title will be put on the graph. The option --*output* writes an output file. The default here is ‘rsp.png’, which the software attempts to write to the working directory.

webhdr_avrgrsp takes the average of the RSP polynomials and outputs to STDOUT.

Seventh: Apply the luminance calibration factor (figure 4-3)

Hdrexpo is a Perl script for adjusting the exposure in HDR images. This is useful for adjusting the luminance values following a spot-meter calibration. The photometric pixel value (in cd/m²) is the product of the pixel value stored in the image body and the exposure value from the header. By simply adjusting the EXPOSURE= line in the header, the luminance values may be adjusted for the whole image.

Eighth: Fix the Radiance header: equiangular fisheye (figure 4-3)

By means of the *–vta* option, the image is rendered as fisheye using 180º for the horizontal and vertical view angle (-vv=180, -vh=180).

D:\Desktop\fisheye_glare_v2a.bash lunes, 09 de septiembre de 2013 13:04

```
            echo "Error: Can't generate HDR image in $d." >&2
            cd ..
            continue
        fi
    else
        # Once you have a good average RSP, use this instead
        # Note that the average RSP is not done by this script.
        # Try something like (run from within ../all_rsp):
        # $ webhdr_avrgrsp 1.rsp 2.rsp 3.rsp > average.rsp

        if [ -f ../all_rsp/$AVRG ];then
            rm -f tmp.hdr
            hdrgen -o tmp.hdr -a -f -r ../all_rsp/$AVRG cropped/*.JPG
        else
            echo "Error: Can't find RSP average file $AVRG (We are in $d)." >&2
            cd ..
            continue
        fi
    fi

    # Apply luminance calibration factor
    webhdr_hdrexpo.pl $CF tmp.hdr > tmp2.hdr
    # Fix the Radiance header: equiangular fisheye
    sed '
7 i\
VIEW= -vta -vh 180 -vv 180 -vp 0 0 0 -vd 1 0 0 -vu 0 0 1
' tmp2.hdr > $hdr

    # Produce a smaller HDR for falsecolor
    pfilt -x $SMALL_DIM -y $SMALL_DIM $hdr > $small

    # Find glare sources in the HDR image
    findglare -r 1000 -p $hdr > $d.glr
    # Derive the DGI
    dgi_f=$(glarendx -h -t dgi $d.glr |cut -f2)
    # Format to one decimal place, if you like
    #dgi=$(printf "%.1f" $dgi)
    # indirect illuminance
    e_ind=$(cat $d.glr |grep -A 1 'BEGIN ind' |tail -n -1 |cut -f3)

    # Evalglare: produce a pic and evalglare.text
    evalglare -b 5 -r 0.1 -c ${d}_evalglare.hdr -d $small > $d.dgp
    #dgp,av_lum,E_v,lum_backg,E_v_dir,dgi,ugr,vcp,cgi,lum_sources,omega_sources,Lveil:
    0.241182 213.153270 869.179337 185.401408 286.723626 18.259886 21.586428 15.482616
    25.017994 1507.765901 0.207812 76.666061
    dgp=$(grep ^dgp $d.dgp |cut -d' ' -f2)
    ev=$(grep ^dgp $d.dgp |cut -d' ' -f4)
    dgi_e=$(grep ^dgp $d.dgp |cut -d' ' -f7)

    # Put the glare indices into a file
    echo -e "$d\t$dgi_f\t$e_ind\t$dgi_e\t$dgp\t$ev" >> ../$GLARE

    # Create FC image and convert to JPG
    falsecolor -log 4 -pal pm3d -n 10 -ip $small > tmp.hdr
    ra_tiff tmp.hdr tmp.tif
    convert -quality 95 tmp.tif ${d}_fc.jpg
```

-3-

figure 4-3: Script “fisheye-glare” (page 3)

Ninth: Produce a smaller HDR for falsecolour (figure 4-3)

Pfilt performs anti-aliasing and scaling on a Radiance picture. The program makes two passes on the picture file in order to set the exposure to the correct average value. *-x res* sets the output x resolution to res. This must be less than or equal to the x dimension of the target device. *-y res* sets the output y resolution to res, similar to the specification of the x resolution above.

Tenth: Find the glare sources and derive the DGI (figure 4-3)

Findglare is a Radiance program which locates the sources of glare in a specific set of horizontal directions by computing luminance samples from the Radiance picture. *Findglare* is intended primarily as a pre-processor for glare calculation programs such as *glarendx*. *Findglare* normally identifies glare sources as directions that are brighter than 7 times the average luminance level. It is possible to override this determination by giving an explicit luminance threshold with the *-t* option.

Glarendx is another Radiance program. It computes the selected glare index type from the given *glarefile* produced by *findglare*. *Glarendx* understands the argument *dgi* as a type and computes de Daylight Glare index. The *–h* option is used to remove the information header from the output.

Eleventh: Produce a file .pic and an evalglare.txt (figure 4-3)

Evalglare determines and evaluates glare sources within a 180° fish-eye-image, given in the Radiance image format (.pic or .hdr). The *–b factor* option defines the threshold factor. If the factor is <= 100 and no task position is given, this factor multiplied by the average luminance in the entire picture is used as threshold for detecting the glare sources (default value = 5). The *-r radius* option searches the radius (angle in radiant) between pixels, where *Evalglare* tries to merge the glare pixels to the same glare source (default value = 0.2 radiant). The *-c filename* option writes a check file in the Radiance picture format.

D:\Desktop\fisheye_glare_v2a.bash lunes, 09 de septiembre de 2013 13:04

```
    # Also convert the HDR to JPG
    ra_tiff $hdr tmp.tif
    convert -quality 95 tmp.tif $d.jpg

    # This is to show you how you can use command-line arguments:
    if [ $SPECIAL -eq 1 ]; then
        echo "I'm doing something special now."
    fi

    # Tidy up
    rm tmp*

    # Go up one level
    cd ..
done

# Hope you get this to work! Good Luck! Axel

#EOF
```

-4-

figure 4-4: Script “fisheye-glare” (page 4)

Twelfth: Put the glare indexes into a file (figure 4-3)

Echo displays a line of text with the results. The *-e* option enables the interpretation of the backslashes escapes.

Thirteenth: Create a FC image and convert to JPG (figure 4-3)

Falsecolor produces a false colour picture for lighting analysis. The input is a Radiance picture. For a logarithmic rather than a linear mapping, the *-log* option can be used, where decades is the number of decades below the maximum scale desired. The *–pal* option provides different colour palettes for *falsecolor*. The current choices are *spec* for the old spectral mapping, *hot* for a thermal scale, and *pm3d* for a variation of the default mapping, *def*. The *–n* option can be used to change the number of contours (and corresponding legend entries) from the default value of 8. If the input picture is given with *–ip* instead of *–i*, then it will be used both as the source of values and as the picture to overlay with contours.

Fourteenth: Convert the HDR to JPG (figure 4-4)

Ra_tiff converts a Radiance picture to/from a TIFF colour or greyscale image.

Convert is a program member of the ImageMagick suite of tools. It is used to convert between image formats as well as resize an image. The *-quality value* option defines a JPEG/MIFF/PNG compression level.

4.1.2. Measurements versus HDR techniques

In order to make the luminance information as accurate as possible, the calculations done by *hdrgen* can be improved by means of two calibrations.

The first calibration lies in adjusting the *response curve* of the camera, which converts the RGB pixel information in a value of brightness. The *response curve* depends on the sensor (photo-sensitive chip) of the camera involved in the registration of the image. The production of these electronic components is never identic. Thus, it is convenient to adjust the response curve to each camera. The predominant light source of the scene also affects decisively the *response curve*. Therefore, it is recommended determining a specific response curve for each camera in relation to each predominant light source. In order to do this calibration, the automatic White Balancing of the camera should be turned off and adjusted to this predominant light source. Axel Jacobs describes the required procedures to define the response curve with precision (Jaloxa, 2011b). The response curve is a polynomial (4-1):

$$y = ax^4 + bx^3 + cx^2 + dx + e \tag{4-1}$$

Its coefficients are stored in a text file with the extension *.rsp*. Table 4-1 shows how it looks like when considering the lighting conditions (sunlight) of the case studies in London, using the Nikon D200. Table 4-2 is equivalent to table 4-2 but related to the case studies in Barcelona, using the Nikon D70.

table 4-1: Coefficients of the response curve (Nikon D200 – Sunlight – London)

	a	b	c	d	e
4	0,67037	0,25553	-0,104959	0,177416	0,001643
4	0,555572	0,383503	-0,120519	0,180593	0,000851
4	0,670544	0,206528	-0,052288	0,175761	-0,000545

The three lines are for the Red, Green, and Blue channels. The first number of each line indicates the order of the polynomial, e.g. the Red channel from this table has the following (4-2) response curve (x is the pixel value):

$$y = 0.67037x^4 + 0.25553x^3 - 0.104959x^2 + 0.177416x + 0.001643 \quad (4\text{-}2)$$

table 4-2: Coefficients of the response curve (Nikon D70 – Sunlight – Barcelona)

	a	b	c	d
3	0,142283	-0,739026	0,319277	-0,003084
3	1,259340	-0,554044	0,297409	-0,002702
3	0,160704	-1,002271	0,400598	-0,005365

Figure 4-5 is a plot of the photometric response curves (corresponding to tables 4-1 and 4-2) which *hdrgen* derived from some image sequences and *webhdr_avrgrsp* averaged. The Red, Green, and Blue channels are plotted separately. As the figure shows, the curves should be monotonically rising from the bottom-left hand corner (0,0) to the top-right hand one (1,1). Occasionally, the curves can be rather wobbly, going down as well as up. This indicates that the RSP function is not good, possibly because the image registration failed, or due to very saturate colours.

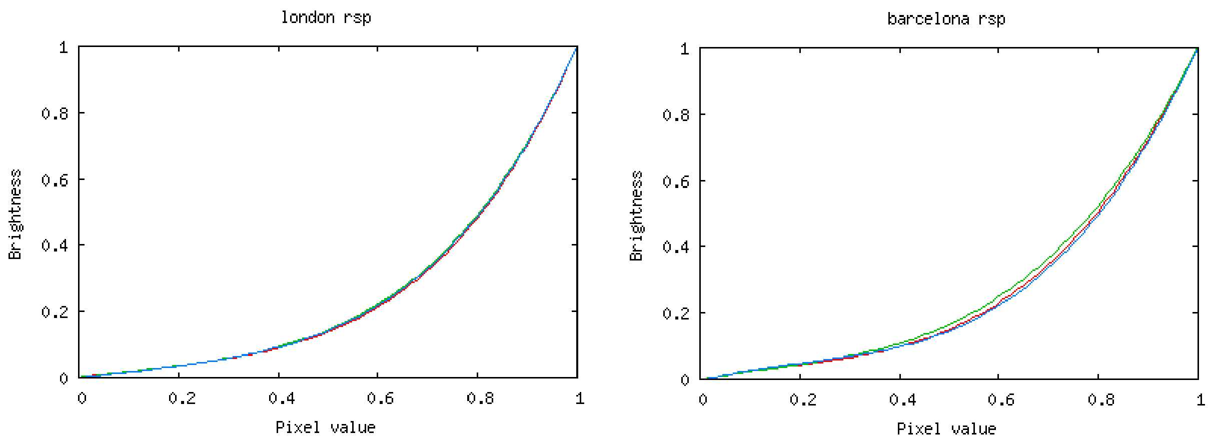


figure 4-5: Plotted response curves: Nikon D200 - Sunlight - London (left) and Nikon D70 - Sunlight - Barcelona (right)

Both response curves correspond to scenes inside two meeting rooms (London and Barcelona), under sunlight conditions. In London, ten sequences corresponding to ten visual fields permitted to obtain an average response curve reliable to be reused for more assessment under the same light conditions. In Barcelona, six visual fields were used for the same purpose. In both cases, the camera settings, which are relevant to determine the exposure value, were: W/B = 5600K, ISO = 400 and Aperture = F5.6. All those settings were maintained to continue with the second calibration procedure and were validated after testing how both procedures worked together.

The second calibration consists in an absolute photometric calibration which compares a reading obtained with a precise instrument to the reading deduced by means of the HDR image. There are two methods to succeed with this calibration.

First method: A luxmeter (Hagner – Model EC) is needed to measure the vertical illuminance at the lens of the camera. Findglare and Evalglare calculate the same vertical illuminance. Thereby, we obtain two readings of the same point. Ideally the two readings should be the same. If they are not, a calibration factor is needed. The calibration factor is simply the ratio of the HDR illuminance over the real illuminance (4-3):

$$CF = \text{Illuminace}_{\text{Real}} / \text{Illuminance}_{\text{HDR}} \tag{4-3}$$

Second method: A luminance meter (Minolta CS-100) is used to measure the luminance of the scene at a few points. By means of the Radiance *ximage* viewer, it is possible to read the luminance of the same points in the HDR image. As it happened with the illuminance, the calibration factor is deduced as ratio of the two measures, the HDR luminance over the real luminance (4-4):

$$CF = \text{Luminance}_{\text{Real}} / \text{Luminance}_{\text{HDR}} \tag{4-4}$$

Table 4-3 (left): Calibration factor using Ev (meeting room in London)

	CF=1,3	
Ev_evalglare	Ev_luxmeter	CF
771	700	0,9
398	350	0,9
1256	1200	1,0
1387	1250	0,9
471	440	0,9
1381	1100	0,8
783	750	1,0
1775	1700	1,0
1708	1600	0,9
717	750	1,0
	average	0,93
	stdev	0,06
	average*CF	1,21
	average*stdev	0,08

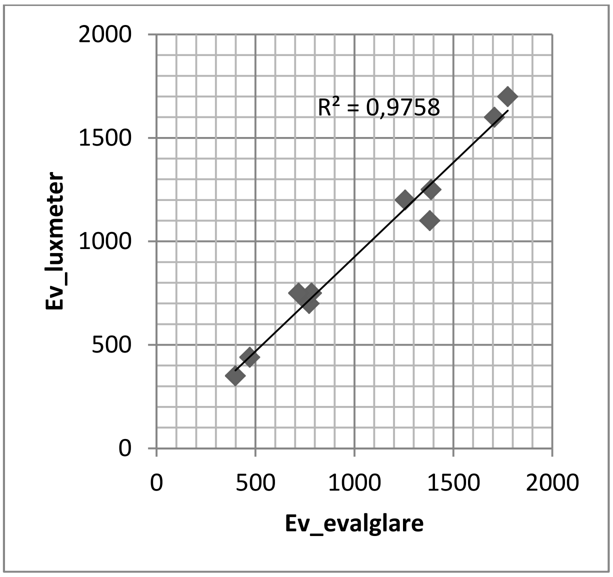


Figure 4-6 (right): Graphic correlation between Ev_evalglare and Ev_luxmeter (London meeting room)

Table 4-3 shows the results obtained when assessing 10 visual fields of the meeting room in London. By means of method 1, the purpose was to determine the calibration factor under different lighting conditions: “low”, “medium”, “high” and “very high” brightness of the scenes. The initial calibration factor was 1.3. This calibration factor was quite accurate for all the different scenes. The calculation of an average calibration factor permitted to adjust the value to 1.21, with a small standard deviation of 0.08.

Figure 4-6 represents the previous results in a graphic. It is useful to identify the different categories of brightness: “low” (under 500 lux), “medium” (around 750 lux), “high” (1200-1400 lux) and “very high” (over 1500 lux). The graphic demonstrates that there is a good correlation when applying a calibration factor between 1.2 and 1.3.

Method 1 was also used for the absolute calibration in Barcelona, using the Nikon D70, under sunlight conditions. The resulting calibration factor was 1.18 and the standard deviation was 0.25. The calibration factor is similar to the one of London. However, the standard deviation is considerably higher. Two aspects could motivate this fact. Firstly, the Nikon D200 (London) is a camera for professional use whereas the Nikon D70 (Barcelona) is a camera for amateur use. Thus, it seems consistent to presume that the sensor's performance of the Nikon D200 is higher. Secondly, the solar access in the room was higher in Barcelona and this fact adds difficulties to the measurements.

Table 4-4 shows the values which were used to determine the calibration factor using method 2. The rows correspond to the ten visual fields which were also used for method 1. The columns are associated to six possible points for which the luminance is registered with the luminance meter and calculated by means of Evalglare. The purpose is to obtain at least the luminance of one interior surface, one sun patch and two portions of sky. If we compare the measurement and the calculated luminance, only some values represented in red are not similar. Most of them correspond to the sun patches. A high degree of specular reflection on the interior surfaces might be the reason to explain the difficulties to obtain precise measurements. Again, the starting calibration factor is 1.3 and, after averaging all the check points, the resulting calibration factor is 1.23, presenting a small standard deviation of 0.11. This value is almost identic to the values obtained using method 1 (average calibration factor of 1.21 and standard deviation of 0.08). Therefore, it is proper to affirm that the absolute calibration is as accurate with method 2 (using the luminances of some points) as it is with method 1 (using the illuminance on the lens). Just because a luxmeter is much cheaper than a luminance meter, method 1 is recommended for common users.

table 4-4: Calibration factor using Ev

	B	C	D	E	F	G	H	I	J	K	L	M							
	MEASUREMENT						EVALGLARE						CF=1,3						
directory	PT_1	PT_2	SUN_1	SUN_2	SKY_1	SKY_2	PT_1	PT_2	SUN_1	SUN_2	SKY_1	SKY_2	B/H	C/I	D/J	E/K	F/L	G/M	
1	710		4800		2700	3300	758		6200		3000	3700	0,9		0,8		0,9	0,9	
2	85	70	4100		2000	2200	83	68	5500		2100	2500	1,0	1,0	0,7		1,0	0,9	
3	120	19	5100	2300	2200	2200	116	16	5150	2300	2200	2300	1,0	1,2	1,0	1,0	1,0	1,0	
4	150		4850	2100	1100	1700	155		5300	2500	1200	2000	1,0		0,9	0,8	0,9	0,9	
5	100	80	3400		1650	2200	108	86	5300		1750	2300	0,9	0,9	0,6		0,9	1,0	
6	740		4500		2500	3300	820		4970		2800	3500	0,9		0,9		0,9	0,9	
7	166	130	3000		2200	2300	185	157	3300		2600	2700	0,9	0,8	0,9		0,8	0,9	
8	270	46	5000	2400	2100	2200	286	45	5200	2200	2200	2200	0,9	1,0	1,0	1,1	1,0	1,0	
9	580	1700	4500	1800	1200	1700	680	1700	4800	1600	1200	1700	0,9	1,0	0,9	1,1	1,0	1,0	
10	190	150	2700		1500	1800	185	140	3500		1600	1900	1,0	1,1	0,8		0,9	0,9	
											average		0,95	1,01	0,86	1,01	0,93	0,93	
											stdev		0,06	0,11	0,11	0,13	0,05	0,06	
											average*CF		1,24	1,31	1,11	1,32	1,21	1,21	1,23
											stdev*CF		0,08	0,15	0,15	0,17	0,06	0,07	0,11

Method 2 was also used for the calibration in Barcelona. The results were: CF=1.27 and stdev=0.28. Again, the standard deviation is more critical in Barcelona. The cause has been argued previously.

4.2. Camera settings and repercussions in glare calculations

The previous chapter has introduced the main issues to succeed with the production of HDR images and the subsequent luminance readings. It focuses the attention in two techniques of calibration which require a special care: response curve and calibration factor.

This chapter insists on the available tools to verify the reliability of the results. For this matter, the function of the program *webhdr_jpgheatmap* is notably relevant. It produces an image from an exposure-bracketed JPG sequence indicating the pixels from which reliable photometric HDR information cannot be derived. This is a sensitive issue for the glare assessments under sunlight conditions. In order to avoid the pixels with unreliable HDR information, it is convenient to work with sequences of nine exposures. Despite that, the range of luminances is often so wide that it is impossible to guarantee simultaneously good readings for the darkest and brightest pixels.

The camera settings permit to adjust the centre of the nine exposures. An option to assure better readings is to shift the centre of the nine exposures to the negative values (-1,-2,-3). This is the way to grant a privilege to the brightest pixels, which are especially relevant because they presumably contain the source of glare. This chapter shows the results (heatmaps and glare calculations) of the same scene registered with different centres of the exposure-bracketed sequences. This time, the rest of settings are not a variable anymore. They are defined as follows:

- Rsp file = london rsp Calibration factor = 1.2
- Aperture = F 5.6 ISO = 400 W/B = 5600K

The purpose is to identify which centre can be reused for other sequences. At the same time, the tests are useful to clarify the repercussion of shifting the centre of the bracketing option in terms of glare calculations. This chapter only shows the data of the London case (Nikon D200) assuming that the Barcelona case (Nikon D70) does not need to be justified due to its similarities.

4.2.1. Control of the heatmap and the bracketing centre

The purpose now is to identify an appropriate centre of the exposure-bracketed sequence when assessing a potentially glaring scene. The chosen scene (figure 4-7) presents a high daylighting contrast. It corresponds to a meeting room facing north where the interior is dark compared to the bright exterior viewed through the window. The experiment starts setting the centre of the bracketing in 0 (shutter speed = 1/350). In this case (table 4-5), the extreme exposures are +4 (shutter speed = 1/20) and -4 (shutter speed = 1/6000). The heatmap alerts that a few blue pixels are likely to have a luminance that is lower than indicated (2.9 cd/m2). Moreover, a much smaller amount of red pixels are likely to have a luminance that is higher than indicated (30876 cd/m2). In order to eliminate the red pixels, three other sequences are tested, shifting the bracketing centre to -1, -2 and -3. The red pixels start to disappear when the centre is adjusted in -2. In this case, the extreme exposures are +2 (shutter speed = 1/90) and -6 (shutter speed = 1/8000). Not surprisingly, there are more blue pixels now. Even if the luminance is lower than indicated, considering the very low value (1.5 cd/m2), these pixels are not supposed to change the glare calculations significantly.

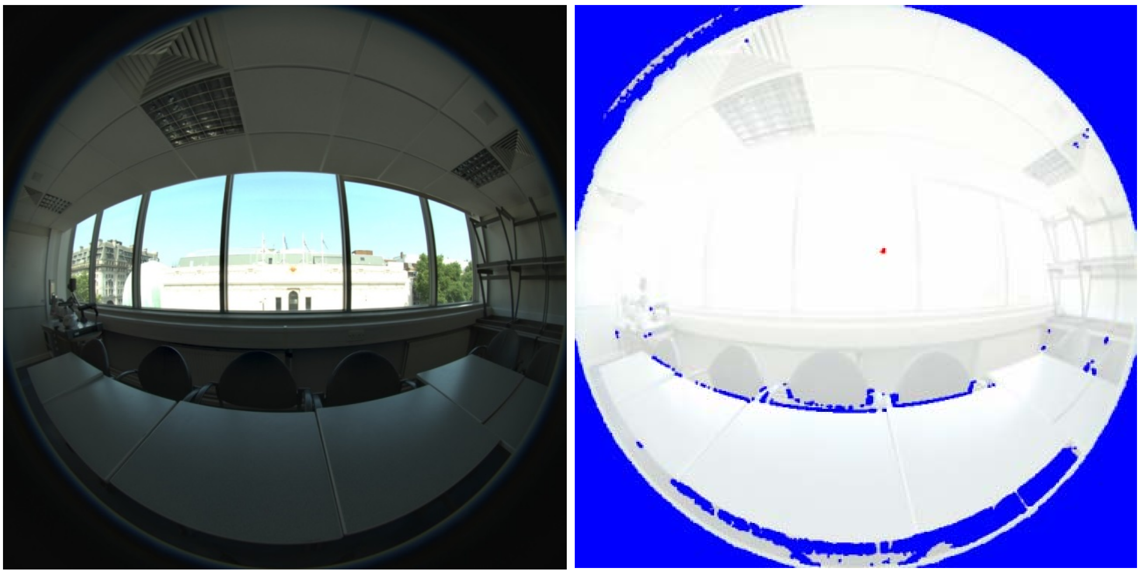


figure 4-7: View through the window in a north facing meeting room (HDR and heatmap)

table 4-5: Auto bracketing of nine exposures centred in 0: EV and the related shutter speed

+4	+3	+2	+1	**0**	-1	-2	-3	-4
1/20	1/45	1/90	1/180	**1/350**	1/750	1/500	1/3000	1/6000

Table 4-6 distinguishes four rows corresponding to the four sequences that were previously mentioned. It compares the real reading of the vertical illuminance (Ev) at the lens to the reading obtained thanks to Evalglare. Furthermore, it presents the results of the DGI and DGP indexes according to two different thresholds.

It is noticeable that calculated Ev increases when the centre of bracketing is shifted to the negative values. This is because the amount of red pixels is reduced, i.e. there are fewer pixels that have a higher luminance than indicated. This means that the value of the luminance of the brightest pixels (sources of glare) increases and, consequently, the value of Ev is higher.

In terms of DGI and DGP calculations, the different positions of the bracketing centre do not provoke significant variations in the results. The DGI results only register one unit of variation and the DGP results only three hundredths. None of those variations implies a different perception of glare. In addition, it is convenient to remark that the DGI index increases slightly when the threshold decreases (Ls>Lav*5). That is because more pixels are included in the glare source. However, there is no repercussion in the DGP results because this index gives a greater weight to Ev.

table 4-6: Comparison of results changing the centre of the bracketing

	meeting room					
			Ls > Lav*7		Ls > Lav*5	
centre_BKT	Ev_luxmeter	Ev_evalglare	DGI_evalglare	DGP_evalglare	DGI_evalglare	DGP_evalglare
0	3600	4032	24	0,44	25	0,44
-1	3600	4120	24	0,44	24	0,44
-2	3600	4194	24	0,45	25	0,45
-3	3600	4571	25	0,47	25	0,47

4.2.2. Problems to control high luminance values

The high luminance values happen when the observer is facing the sun's position. Basically the brightest pixels are the portions of sky in or near the sun's halo and the inside surfaces which reflect the sun beams with specular properties. These situations occur when the solar elevation is low (in winter, south facing interiors; in summer, east, west and north facing interiors).

In order to obtain the reliable luminance readings corresponding to the brightest pixels, the bracketing centre can be shifted to the negative values. Each camera has different options and limits.

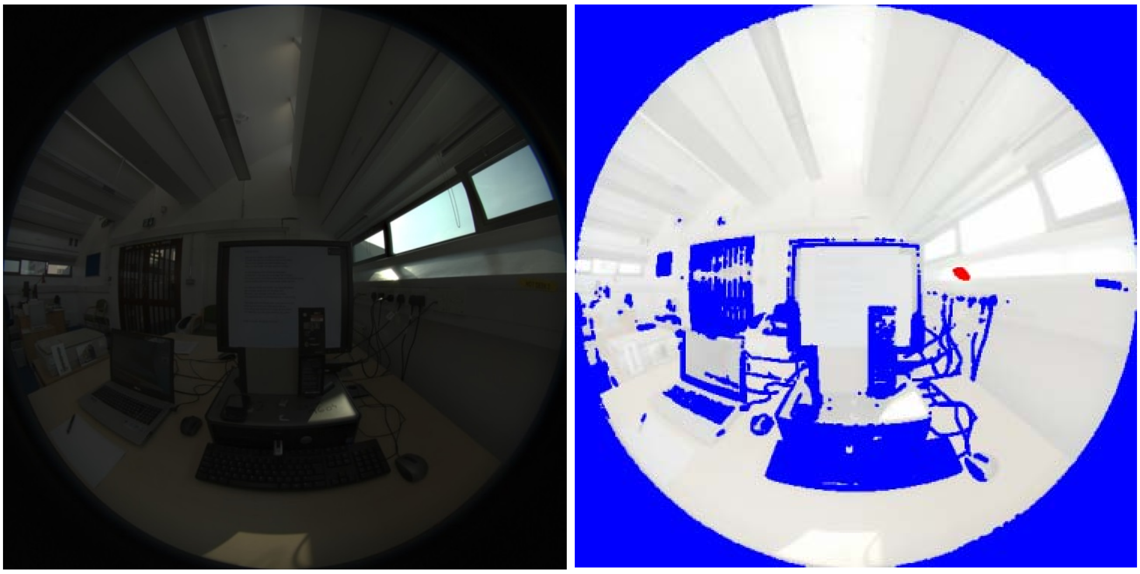


figure 4-8: Office desk at the sunset with specular reflexions inside (HDR and heatmap)

table 4-7: Auto bracketing centred in -4

0	-1	-2	-3	**-4**	-5	-6	-7	-8
1/100	1/200	1/400	1/750	**1/1600**	1/3200	1/6400	1/8000	1/8000

The Nikon D200, which was used for the assessments in London, permits to centre the bracketing in -5. According to this centre, the nine exposures are distributed and the extreme EVs are -1 and -9. If the aperture priority mode is set, the camera adjusts the each exposure to the corresponding shutter speed.

Even though the centre of the bracketing can be set in -5, the experiments of this chapter are useful to demonstrate that this setting is inappropriate (using the Nikon D200). Because the fastest shutter speed is 1/8000, when assessing a bright scene, the camera repeats the same exposure in the darkest pictures of the sequence (table 4-7) and does not improve the luminance readings of the brightest pixels. The figure 4-8 is related to bracketing setting of table 4-7. The heatmap identifies in red the controversial pixels. When the bracketing centre is set in -3, only one exposure is shot with a shutter speed of 1/8000. The maximum luminance of the red pixels is 65288 cd/m2. If the centre is -4 (table 4-7), the maximum shutter speed (1/8000) is repeated in two exposures and the maximum luminance reading is 68622 cd/m2. Consecutively, if the centre is set in this most negative value of -5, three exposures are identical and the maximum luminance reading is 67798 cd/m2. Therefore, if the centre is set in -4 or -5, the readings have not improved for the brightest pixels while the readings of the darkest pixels get worse (more blue pixels in the heatmap).

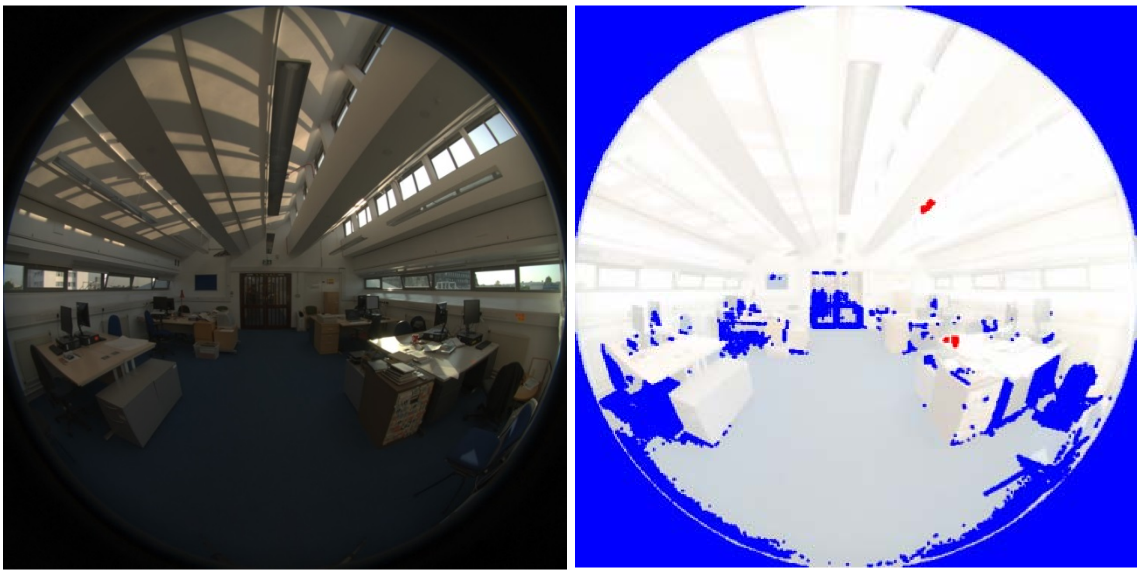


figure 4-9: Office corridor at the sunset with specular reflexions inside (HDR and heatmap)

table 4-8: Auto bracketing centred in -3

+1	0	-1	-2	**-3**	-4	-5	-6	-7
1/40	1/80	1/160	1/320	**1/500**	1/1250	1/2500	1/5000	1/8000

In order to recommend a bracketing centre more experiments are necessary. Another scene was analysed (figure 4-9 and table 4-8) and the results can be compared to the previous case. Again, the maximum shutter speed appears when the bracketing centre is set in -3. The corresponding maximum luminance was 74363 cd/m2. There was not improvement when the centre was -5. Then, Lmax was 71022 cd/m2.

In terms of glare calculations, it is appropriate to affirm that there is almost none repercussion when the bracketing centre is shifted. Table 4-9 compares the results of the two previous experiments. They are almost identical. Therefore, after these experimental studies, it is recommended to set the bracketing centre in -3, or even in -2. These case studies are also useful to identify the maximum luminance that has been read by the sensor of the Nikon D200 (75000 cd/m2 aprox).

table 4-9: Comparison of results changing the centre of the bracketing (2 visuals fields: “office desk” and “office corridor”

	office desk					
			Ls > Lav*7		Ls > Lav*5	
centre_BKT	Ev_luxmeter	Ev_evalglare	DGI_evalglare	DGP_evalglare	DGI_evalglare	DGP_evalglare
-2	1750	1749	25	0,32	24	0,32
-3	1750	1813	25	0,33	25	0,33
-4	1750	1871	25	0,33	25	0,33
-5	1750	1703	25	0,32	25	0,32
	CF=1,3	ok: BKT -2				
	office corridor					
			Ls > Lav*7		Ls > Lav*5	
centre_BKT	Ev_luxmeter	Ev_evalglare	DGI_evalglare	DGP_evalglare	DGI_evalglare	DGP_evalglare
-3	1470	1466	22	0,29	22	0,29
-5	1470	1451	22	0,29	21	0,28
	CF=1,3	ok: BKT -3				

4.3. The definition of a glare source and its impact in the glare calculations using Radiance and Evalglare

The previous chapter discusses the best settings of the camera to produce an HDR image, which is suitable for the luminance measurements. This chapter confers how to deal with the next step, which is to compute the pixel information to calculate the glare indexes of the scene. As it has been introduced, this task is done by means of the Radiance commands and Evalglare. Basically, both calculate considering the glare metrics. But previously, one decision needs to be taken into account. It is necessary to define the pixels considered as part of the glare source and those included in the background.

Radiance processes the calculation using *findglare* first and *glarendx* afterwards. *Findglare* is the program which defines the pixels that are considered as source of glare. Then, *glarendx* is used to proceed with the calculation of a precise glare index. *Findglare* offers different options to define the glare source. These options should be selected according to the assessments. *Findglare* normally identifies glare sources as directions that are brighter than 7 times the average luminance level. It is possible to override this determination by giving an explicit luminance threshold with the -t option. It usually works best to use the ’l’ command within *ximage* (radiance displayer) to decide what this value should be. The idea is to pick a threshold that is well above the average level but smaller than the source areas. If the sources in the scene are small, it may be necessary to increase the default sample resolution of *findglare* using the –r option. The default resolution is 150 vertical samples and a proportional number of horizontal samples. If besides being small, the sources are not much brighter than the threshold, the -c flag should be used to override *findglare’s* default action of absorbing small sources it deems to be insignificant.

Evalglare implements three algorithms which are valid to detect the pixels included in the glare source. The first option (*-b value* ≤ 100 and no *–t* used) is to define the glare pixels in comparison to the average luminance of the whole scene. Every pixel brighter than x-times of the average luminance is treated as glare source (Radiance default = 7). The second option (*-b value* ≥ 100) is to define a fixed value threshold. If the two first options are also included in *findglare*, the third option is specific of *evalglare*. This option (*-b value* ≤ 100 and *–t* used) needs first to define an area of task location within the picture. Evalglare calculates the “task luminance” and treats all pixels higher than x-times of the task luminance as glare source. Depending on the “size” of the task, the adaptation level is taken into account. *Evalglare* also includes a -r parameter to merge the “glare pixels” to a glare source. The –r parameter defines a search diameter (not a radius) to indicate how large the glare source is. Evalgare adds two more options to the glare source treatment. The smoothing option (-s) encloses to the glare source the darker zones “within” a detected glare source. The spot extraction (-y) extracts of the glare source the “peaks” of very high luminances to an extra glare source.

In this chapter, the results of both programs (Radiance and Evalglare) are tested and compared. Some parameters, or options, which are used to define the glare source, remain constant while others are defined as variables. The assessments pretend to predict if the users will change the lighting conditions due to glaring situations when viewing the whole space. In these situations, the eye adaptation to the average luminance of the scene is decisive. That is the reason why the algorithm used in this research to define the glaring pixels is the one which compares them to the average luminance of the scene (and not to the average of luminance of a task, or, to an absolute luminance value, which is always difficult to argue). Two thresholds are tested (chapters 4.3.1 and 4.3.2): 5-times and 7-times brighter than the average luminance. The influence of the size of the glare source is also tested using the –r option of *evalglare* (chapter 4.3.3). This chapter does not test the influence of the smoothing option and the spot extraction of *evalglare*. The research assumes that is unnecessary because most of the glare sources will have clearly defined surfaces (sun patches and portions of sky). At the end of the chapter, it will be possible to recommend the best settings to define the glare sources according the case studies. Then, it will be possible to judge different scenes under the same parameters of glare source detection.

4.3.1. DGI and DGP using Evalglare with two thresholds

Two experiments are carried out to test the sensibility of the glare calculations (DGI and DGP indexes) when the sources of glare are defined by two different thresholds (Lav*7 and Lav*5). The two experiments pretend to be clearly different in terms of daylighting conditions and glare results. The first experiment (figure 4-10) occurs in an office space, with multiple relatively small windows. Thus, it is a multi-side lit space with bright sources of light that create a well-balanced daylit ambient. In opposition, the second experiment (figure 4-10) analyses the results in a side lit space with a bright view through the window which contrasts with a dark interior.

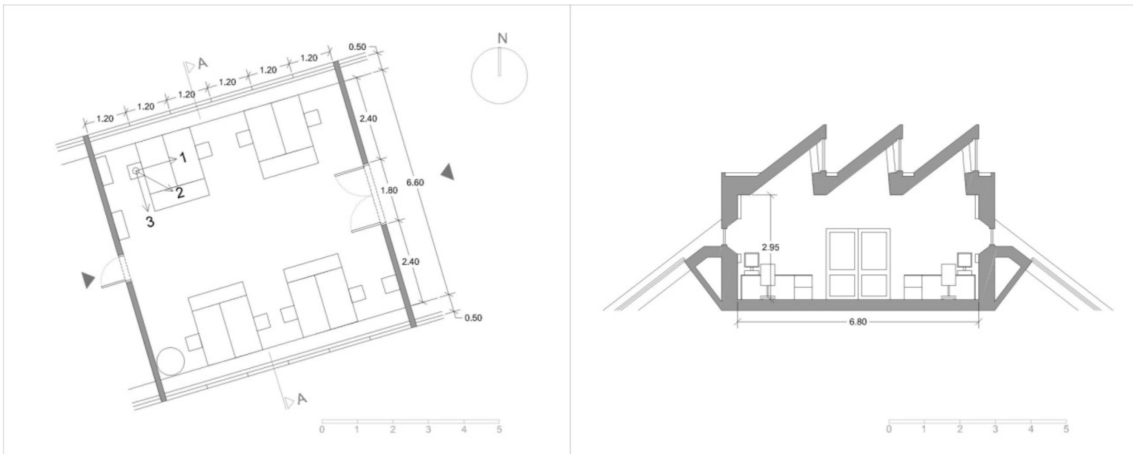


figure 4-10: Plan and section of the room 612, 6th floor, SABE, Westminster University, London (position and view direction of the three tested visual fields)

In more detail, the first experiment (figure 4-10) analyses the results of three visual fields in an office space corresponding to three common sights: (1) doing a task looking at the screen, (2) looking the whole interior space, and, (3) relaxing and viewing the outdoor landscape. The degree of glare of the three scenarios is clearly different. The DGI results (table 4-10) register very often differences of three or more units. The assessments related to these three visual fields are repeated eleven times under similar daylight conditions; namely, at similar hours in consecutive days under clear blue skies. Thus, it is possible to analyse the constancy of the results and to understand the repercussion of the two different thresholds (Lav*7 and Lav*5).

table 4-10: Comparison of the Evalglare results (DGI and DGP) changing the thresholds (Lav*7 and Lav*5), in an office space (repetition of 3 visual fields at different hours).

	FINDGLARE	EVALGLARE				
directory	DGI_Lav*7	DGI_Lav*7	DGI_Lav*5	DGP_Lav*7	DGP_Lav*5	Ev_evalglare
1	12	10	13	0,21	0,22	838
2	16	14	15	0,22	0,22	754
3	20	19	19	0,24	0,24	764
4	16	15	15	0,23	0,23	1015
5	18	16	15	0,23	0,23	1056
6	20	18	19	0,24	0,24	1006
7	11	10	12	0,21	0,22	859
8	15	13	13	0,21	0,22	786
9	19	18	18	0,23	0,23	695
10	15	13	14	0,22	0,23	989
11	15	14	14	0,22	0,22	907
12	19	18	18	0,23	0,23	732
13	14	12	13	0,22	0,22	904
14	16	15	15	0,22	0,22	808
15	19	18	18	0,23	0,23	704
16	11	9	12	0,21	0,22	862
17	15	14	14	0,22	0,22	844
18	19	18	18	0,23	0,23	702
19	12	10	13	0,21	0,22	869
20	15	13	14	0,22	0,22	781
21	19	18	18	0,23	0,24	714
22	12	11	12	0,21	0,21	832
23	17	15	15	0,22	0,22	822
24	20	19	19	0,24	0,24	761
25	12	11	13	0,22	0,22	892
26	18	16	17	0,23	0,23	888
27	20	19	20	0,25	0,25	814
28	13	13	13	0,23	0,23	1131
29	18	16	16	0,24	0,25	1239
30	21	19	19	0,26	0,26	1203
31	17	15	16	0,23	0,23	1013
32	17	16	16	0,22	0,22	794
33	21	19	19	0,25	0,25	936

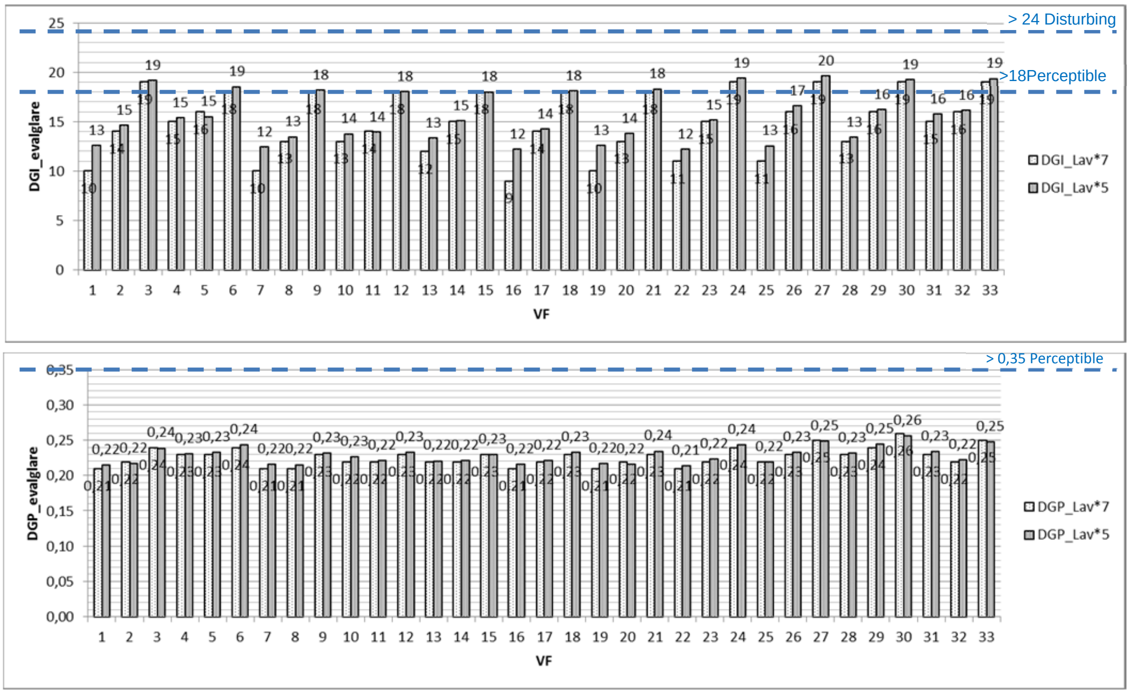


figure 4-11: Graphic comparison of the Evalglare results (DGI and DGP) changing the thresholds (Lav*7 and Lav*5), in an office space (repetition of 3 visual fields at different hours)

The differences between the results of the DGI index are irrelevant when shifting from one threshold to the other. Only 4 of the 33 results exceed 1 unit of difference. In these cases, the difference equals 2 or 3 units, which very often does not change how the experience of glare is classified. It is appropriate to remember that there are 6 units of difference between the perception of glare described as perceptible (DGI=18) and the one considered as disturbing (DGI=24).

Analysing the results of the DGP index, the repercussion of the two thresholds appears as irrelevant. Only 6 of the 33 results present a very small difference of 0.01 units. The difference never exceeds that value and can be considered as insignificant in terms of glare perception.

The calculations of the DGP index are less sensitive to the definition of the glare source than those of the DGI index. This fact, which was presumable according to the formulations of each index, has been quantified thanks to this first experiment with very low values of glare (barely perceptible). But, will it be the same if the scenes are more glaring? The second experiment (figure 4-12) pretends to answer that question.

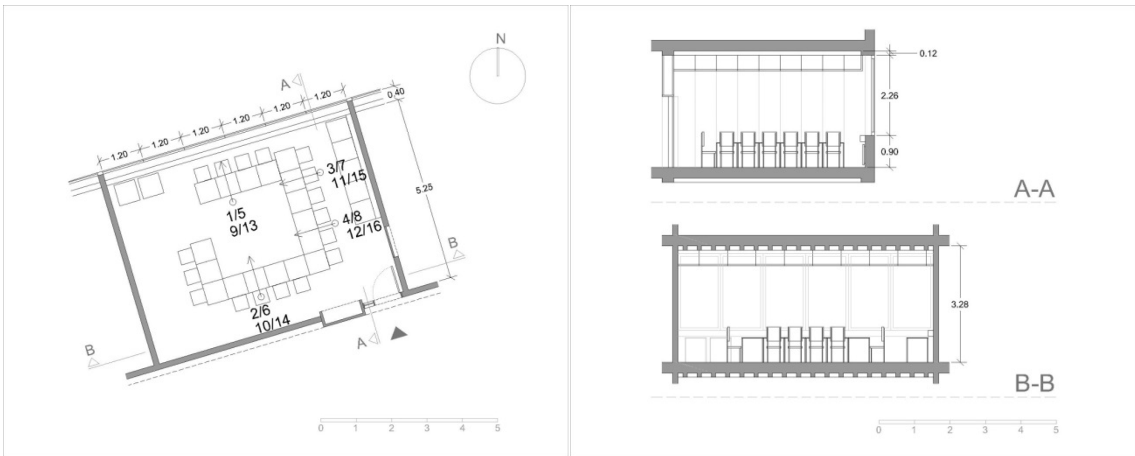


figure 4-12: Plan and section of the room M327, 3rd floor, SABE, Westminster University, London (position and view direction of the four tested visual fields)

In particular, the second experiment proposes the study of four visual fields in a north facing room. Two variables might change the lighting conditions (table 4-11). The first variable is related to the position of the roller screens, characterized by a very low transmittance: in “shading NO”, the screens are up and the view through the window is openly permitted; instead, in “shading YES”, the screens are down and the view is restricted to the central windows.

table 4-11: Comparison of the Evalglare results (DGI and DGP) changing the thresholds (Lav*7 and Lav*5), in a north-facing classroom (4 visual fields under different lighting conditions)

	FINDGLARE	EVALGLARE					
directory	DGI_Lav*7	DGI_Lav*7	DGI_Lav*5	DGP_Lav*7	DGP_Lav*5	Ev_evalglare	conditions
1	24	25	25	0,43	0,43	3742	
2	28	26	26	0,34	0,34	1831	shading NO
3	19	18	19	0,26	0,25	1201	light OFF
4	20	16	16	0,23	0,22	697	
5	21	24	25	0,40	0,41	3420	
6	27	25	26	0,34	0,34	1961	shading NO
7	17	17	18	0,25	0,24	1109	light ON
8	18	15	15	0,22	0,22	681	
9	26	25	25	0,36	0,35	2365	
10	29	26	26	0,30	0,30	890	shading YES
11	21	17	18	0,22	0,23	484	light OFF
12	20	17	17	0,23	0,23	435	
13	25	25	25	0,37	0,36	2569	
14	28	25	25	0,29	0,29	894	shading YES
15	20	17	17	0,22	0,22	520	light ON
16	19	16	16	0,22	0,22	417	

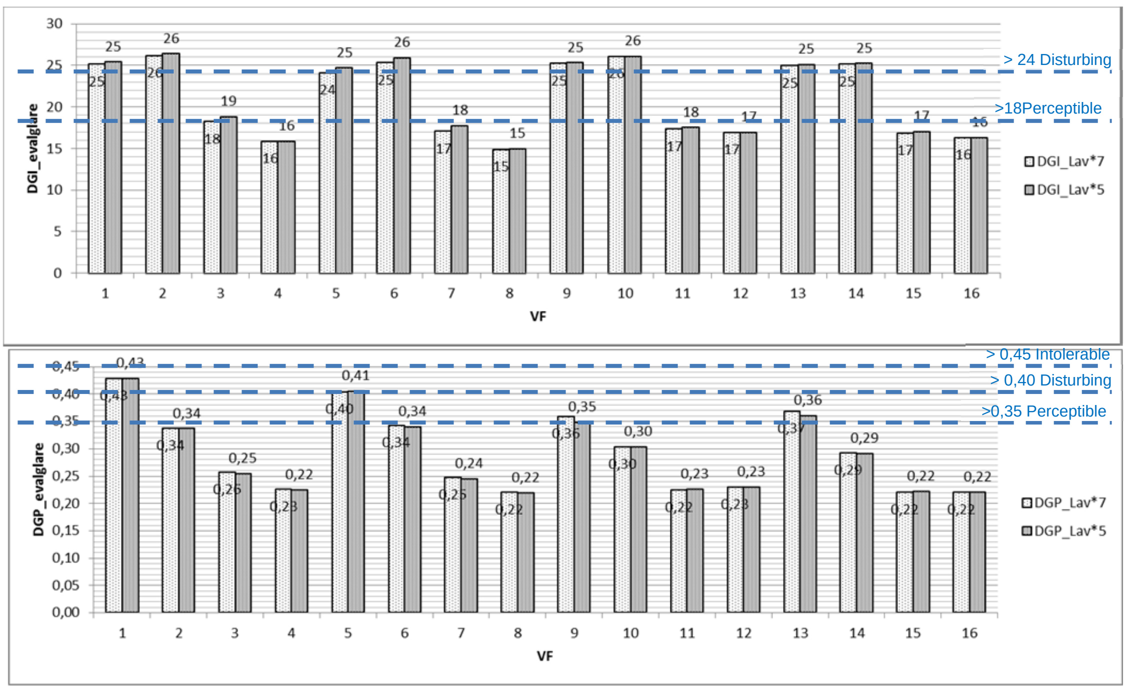


figure 4-13: Graphic comparison of the Evalglare results (DGI and DGP) changing the thresholds (Lav*7 and Lav*5), in a north-facing classroom (4 visual fields under different lighting conditions)

The second variable mentions the presence of artificial light ("light ON" and "light OFF"). The results are organised in groups of four rows in agreement with the four visual fields.

The first row of the four (directories 1/5/9/13) corresponds to the first visual field (perpendicular and near to the window). Consecutively, the second row (directories 2/6/10/14) describes the second visual field (perpendicular and far from the window), the third row (directories 3/7/11/15) is associated to the third visual field (parallel and near to the window), and finally, the fourth row (directories 4/8/12/16) ends with the fourth visual field (parallel and far from the window).

The multiple lighting situations create a wide variety of illuminance values at the lens, grouped around four values (approximately 3500/2000/1000/500 lux). The DGP results react in consequence describing completely different experiences of glare (perceptible, disturbing and intolerable). Likely, the DGI results are strongly influenced by the position of the glare source into the visual field. The visual fields looking through the window in perpendicular register results around 25. However, the two visual fields in parallel to the window are responsible of values around 17.

Despite the variety of lighting conditions in this second experiment, the results of the glare calculations are not significantly affected when the threshold definition varies between Lav*5 and Lav*7. The constancy is even higher if we compare with the results of the first experiment. Here the results of 16 visual fields can be compared. Almost all of them present identical results. Looking at the DGI calculations, only five results present a small difference of 1 unit. The repercussion is even less noticeable if the DGP results are pointed out. Only six results display the minimum possible difference (0,01 units).

In conclusion, the two experiments are useful to figure out how low is the impact of changing the threshold from Lav*5 to Lav*7 in most cases. Apparently, very often the luminance of the glare sources is clearly above both thresholds. Then, slightly the same pixels are considered as sources of glare and there is no change in the glare results.

4.3.2. DGI using Radiance tools and Evalglare (with the same threshold)

The purpose of the previous chapter was to compare the results of the glare index calculations (DGI and DGP) using Evalglare with two different thresholds for detecting the pixels which are considered as sources of glare (Lav*5 and Lav*7). The present chapter pretends to compare the results (only DGI) with the same threshold (Lav*7 is fixed) but using the two different programs: firstly, Radiance (*Findglare* + *Glarendx*), and secondly, *Evalglare*. Even if the two programs are executed using the same threshold, the results might be different because, besides the threshold option, each program has its own options to identify the pixels included in the sources of glare.

The first tests (tables 4-12 and 4-13) of this chapter analyse the same assessments of the previous chapter but using certain options which do not differ too much of the default settings. As said above, the threshold option (*-t* in both programs) is set in Lav*7. However, the *-r* option is always active in both programs but used for different purposes. In *Findglare*, the *-r* option increases the default sample resolution (150 vertical samples and a proportional number of horizontal samples). It may be necessary if the sources of glare in the scene are small. From the beginning it may be convenient to increase the default sample resolution if we look for the finest results. For the following assessments, the *-r* option is set in 1000. Instead, in *Evalgalre*, the *-r* option defines a search radius (angle in radians) between pixels, where program tries to merge the glare source pixels to the same glare source. The default value is 0.2 radians. *Findglare* do not offer this merging option. If the purpose of this chapter is to test if equal results are possible with different calculation programs, it is thought convenient to reduce slightly the search radius, changing it to 0.1 radians.

Table 4-12 is associated to the experiment in the classroom subjected to different lighting conditions. The DGI results do not seem to be consistent if we compare the calculations using both programs. Many results differ considerably: 3 or 4 units are too much for a formulation which includes a logarithm. In most of the situations the results, calculated using *Evalglare,* are lower. However this should not be identified as a rule because, in some evaluations, the results of *Evalglare* become higher.

table 4-12: Comparison of the results (DGI) of Findglare and Evalglare, using the same threshold (Lav*7), in a north-facing classroom (4 visual fields under different lighting conditions)

	DGI_Lav*7				
directory	Find	Eval	E - F	Ev_eval	conditions
1	24	25	1	3742	shading NO light OFF
2	28	26	-1	1831	
3	19	18	-1	1201	
4	20	16	-4	697	
5	21	24	3	3420	shading NO light ON
6	27	25	-2	1961	
7	17	17	0	1109	
8	18	15	-4	681	
9	26	25	0	2365	shading YES light OFF
10	29	26	-3	890	
11	21	17	-4	484	
12	20	17	-4	435	
13	25	25	0	2569	shading YES light ON
14	28	25	-3	894	
15	20	17	-3	520	
16	19	16	-3	417	

table 4-13: Comparison of the results (DGI) of Findglare and Evalglare, using the same threshold (Lav*7), in an office (3 different visual fields at different moments)

	DGI_Lav*7			
directory	Find	Eval	E - F	Ev_eval
1	12	10	-2	838
2	16	14	-2	754
3	20	19	-1	764
4	16	15	-1	1015
5	18	16	-2	1056
6	20	18	-2	1006
7	11	10	-1	859
8	15	13	-2	786
9	19	18	-1	695
10	15	13	-2	989
11	15	14	-1	907
12	19	18	-1	732
13	14	12	-2	904
14	16	15	-1	808
15	19	18	-1	704
16	11	9	-2	862
17	15	14	-1	844
18	19	18	-1	702
19	12	10	-2	869
20	15	13	-2	781

21	19	18	-1	714
22	12	11	-1	832
23	17	15	-2	822
24	20	19	-1	761
25	12	11	-1	892
26	18	16	-2	888
27	20	19	-1	814
28	13	13	0	1131
29	18	16	-2	1239
30	21	19	-2	1203
31	17	15	-2	1013
32	17	16	-1	794
33	21	19	-2	936

Table 4-13 repeats the same calculation in an office space. This time the lighting conditions do not pretend to change. The same three visual fields are tested eleven times under similar lighting conditions. The distribution of light is now well balanced and the DGI results are not so high. Consequently, the differences are lower (1 or 2 units) but, even so, the results are rarely identical. However, in this case a rule is constant: the Evalglare results are always lower.

The second test (table 4-14) changes the procedure. The assessment selects three visual fields of the first scene (directories 1 to 3) and four visual fields of the second scene (directories 5-8). They are selected because they presented previously the highest differences in the results. The purpose is to test the results using different options for both, Findlgare and Evalglare, in order to find the combination of options that makes the results converge. Once more, the threshold option is the only which never changes (always Lav*7).

The use of the –r option becomes critical for both programs. Table 4-14 shows how the *–r* option of *Findlgare* increases from the left columns to the right columns (from 150 to 2000), while the *–r* option of *Evalglare* decreases (from 0.2 to 0.01). Progressively, the calculations are more detailed. *Findglare* improves the sample resolution and *Evalglare* ends calculating all the pixels separately as individual glare sources with their specific luminance and position.

Another *Findglare* option is used. It is the *–c* flag which is used to override *Finglare's* default action of absorbing small sources it deems to be insignificant. Alike, when calculating pixel by pixel, *Evalglare* disables automatically the peak extraction option (-x) and the smoothing function (-s), which is normally disabled by default. The peak extraction option extracts the luminance peaks to separate glare sources and the smoothing option counts initial non-glare source pixels to glare sources, when they are surrounded by a glare source.

Analysing the *Findglare* columns, the results are notably different when the –r option changes from 150 to 1000, specifically in the most glaring scenes. Adding the –c option the results are slightly modified (1 unit in all the scenes). Finally, when the –r option changes from 1000 to 2000, practically there is no change (only two scenes change their results in 1 unit).

The *Evalglare* columns present a few differences of 1 to 2 units when the -r option changes from 0.2 to 0.1. Similar differences are found when -r changes from 0.1 to 0.05. But the biggest changes occur in the last column that implies that the calculations are done pixel by pixel, without adding the smoothing and the peak extraction options. In that moment, the results of *Evalglare* are almost identical to the results of *Findglare*.

table 4-14: Comparison of the results (DGI) of Findglare and Evalglare, using the same threshold (Lav*7) but using different *–r* options (Findglare and Evalglare) and the *–c* option of Findglare

directory	Find	Eval	E-F	Find	Eval	E-F	Find	Eval	E-F	Find	Eval	E-F
1	13	9	-4	12	10	-3	13	11	-2	14	12	-2
2	15	14	-1	16	14	-1	17	16	-1	17	17	0
3	20	19	-1	20	19	-1	21	19	-1	21	21	0
5	17	24	7	21	24	3	24	24	0	24	25	1
6	25	25	1	27	25	-2	27	25	-2	28	28	1
7	18	15	-3	17	17	0	18	17	-1	18	18	0
8	15	14	-1	18	15	-4	19	17	-2	19	19	0
	-t 7 -r 150	-t 7 -r 0.2		-t 7 -r 1000	-t 7 -r 0.1		-t 7 -r 1000 -c	-t 7 -r 0.05		-t 7 -r 2000 -c	-t 7 -r 0.01 -x	

4.3.3. Evalglare: influence of the radius option

The previous chapter states the effects of the multiple options of Findglare and Evalglare when calculating the index DGI. The *–r* option is identified as very relevant to the results. In the specific case of Evalglare, when the radius is reduced to the minimum value, the calculation is generated pixel by pixel. Apparently, it is the best option to obtain equal results to those calculated by Findglare under the highest resolutions, i.e. the highest values of the *–r* option of Findlgare.

However, calculating pixel by pixel seems far from the features of the human's vision. It is appropriate to speculate that the vision "understands" the lighting information as ensembles of surfaces within the visual field. Therefore, the purpose of this chapter is to identify the value of the *–r* option of Evalglare which creates ensembles of glare sources that are similar to those of Findglare using "standard options" (r=1000 and without the use of c). That is why this chapter adds one relevant aspect in the results; as tables 4-15 and 4-16 show, the number of the calculated glare sources appears in the last two columns.

table 4-15: Comparison of the results (DGI and the number of glare sources), using specific settings for Findglare and Evalglare.

Camera	Evalglare options		DGI		nº glare sources	
BKT centre	(-b) option	(-r) option	DGI_findglare	DGI_evalglare	nº_findglare	nº_evalglare
-2	7 (findglare)	0,09	15,68	15,31	13	12

Table 4-15 shows the particular settings which are responsible of the calculation of 12 glare sources in Evalglare. The software creates an image (right side of figure 4-14) to represent the sources of glare with colours. The experiment consists in using the same visual field (figure 4-14) to repeat the glare calculations whereas the Evalglare options (radius and threshold) are modified and compared to the "standard options" of Findglare (table 4-16). Likewise, the experiment considers the influence of two different bracketing centres for the sequences of pictures that create the HDR image (centre of BKT in -2 or -3).

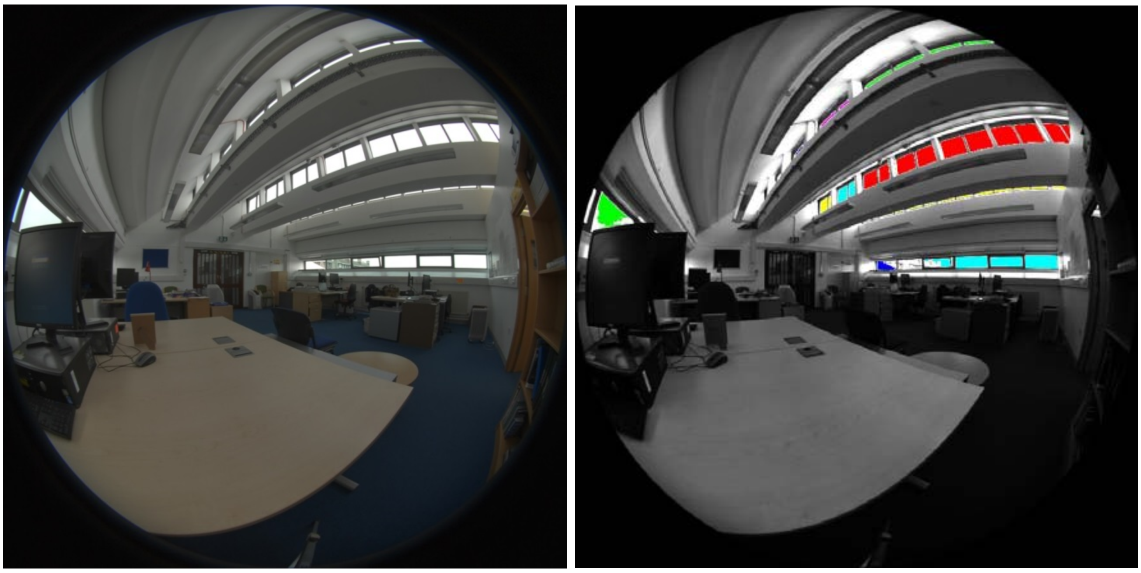


figure 4-14: Visual field used to test the different settings: centre, threshold option (-b) and radius options (-r) of Evalglare (left: HDR image; right: Evalglare image representing the glare sources with colours)

The two first rows of table 4-16 offer quite similar results of DGI. Apparently, it is fortuitous because the thresholds to identify the glare sources do not correspond (Lav*5 with Evalglare and Lav*7 with Findglare). Furthermore, there is a notable disagreement in the number of glare sources (13 using Findglare; 25 using Evalglare).

table 4-16: Comparison of the results (DGI and the number of glare sources), using Findglare and Evalglare, testing different settings: BKT centre, threshold option (-b) and radius options (-r) of Evalglare.

Camera	**Evalglare options**		DGI		nº glare sources	
BKT centre	(-b) option	(-r) option	DGI_findglare	DGI_evalglare	nº_findglare	nº_evalglare
-2	5 (default)	0,05	15,68	15,78	13	25
-3	5 (default)	0,05	15,87	16,00	13	25
-2	7 (findglare)	0,20	15,68	14,67	13	8
-3	7 (findglare)	0,20	15,87	14,86	13	8
-2	5 (default)	0,20	15,68	14,12	13	8
-3	5 (default)	0,20	15,87	14,30	13	8
-2	7 (findglare)	0,10	15,68	14,96	13	10
-3	7 (findglare)	0,10	15,87	15,18	13	9
-2	7 (findglare)	0,09	15,68	15,31	13	12
-3	7 (findglare)	0,09	15,87	15,53	13	12

The experiment resumes until finding the last two rows (depicted in red) offering quite consistent results. Using the same threshold (Lav*7), a similar number of glare sources (12 and 13) is identified and, equally, the results of the index DGI (considering the two BKT centres) are quite similar if they are compared with those of Findglare. Therefore, this experiment is useful to recommend the following settings for the options of Evalglare: a threshold equal to Lav*7 and a radius value of 0.09.

Even so, it is convenient to remark that this experiment studies the implications using one single visual field. Probably, more flexibility for the settings of these options might be needed. Nonetheless, the experiment is useful to identify an accurate order of magnitude to obtain reliable results.

4.4. Conclusions

The previous chapters have been useful to justify all the settings which are convenient to obtain accurate measurements of the luminances within a visual field and reliable calculations of the glare indexes (DGI and DGP). The settings are basically related to three aspects. First, it is specified how to configure the camera before taking the sequence of pictures needed to create the HDR image. Second, it is described how to calibrate the measurements using Webhdrtools. And, finally, the third aspect sets up which are the options and their values, when using Findglare and Evalglare, to calculate the glare indexes. Below, a summary of all these settings is presented.

In relation the first aspect, the settings are:

“White Balance”: the automatic white balancing is turned off. Instead, the white balance is fixed in 5200K (Direct Sunlight). The manual of both cameras (Nikon D200 and D70) indicates that this temperature is appropriate for the pictures with subjects lit by direct sunlight.

“ISO sensitivity” is the digital equivalent to the film speed of the analogical photography. The higher the ISO sensitivity, the less light needed to make an exposure, allowing higher shutter speeds or smaller apertures. In addition, the higher is the ISO sensitivity, the more likely the pictures are subject to “noise” in the form of randomly-spaced, brightly-coloured pixels. The value is set in 400, which is appropriate for daylighting even if the scene starts to be dark.

“Aperture”: the focus mode is set up in manual, giving priority to the aperture. It is the way to assure that the depth of field does not change when the pictures are taken to compose the HDR image. The aperture of f/5.6 guarantees accurate results in terms of focus in a wide range of scenarios.

“Bracketing centre”: the chapters 4.2.1 and 4.2.3 have given many details to go further in the implications of choosing different centres of bracketing. After many tests, in scenarios lit by direct sunlight, it is demonstrated that centering the bracketing in -2 or -

3 is a good solution. Thereby, a sequence of images is obtained avoiding repeated exposures with the same shutter speed. The shifting of the centre from -2 to -3 does not represent relevant changes in the results of the glare indexes.

According to the second aspect, the settings are:

“Response curve”: systematic tests were used to obtain an average polynomial which is represented with a response curve. The order of the polynomial function and its coefficients are stored in a file with an rsp extension. Further details are given in chapter 4.1.2. Two files are used to assess the case studies. They correspond to each one of the two cameras (Nikon D200 and Nikon D70). Both files are deduced after several trials which were done under sunlight conditions.

“Calibration factor”: as the response curve, the calibration factor depends on the lighting conditions. Comparing the illuminance and luminance results with the measurements with a luxmeter and a luminance meter, the calibrations factor are 1.3 for the case studies in London and from 1.1 to 1.3 for the case studies in Barcelona. In the second location, the sunlight conditions were more extreme due to the orientation of the spaces. That reason justifies more variability on the calibration factor.

Finally, the settings related to the third aspect are:

In the calculations of the glare indexes, the following settings are responsible for the identification of the pixels which are taken into account as sources of glare or as part of the background. The chapters 4.3.2 and 4.3.3 identify two options of Findglare and Evalglare (threshold and radius) as especially relevant to the results. For the other options, which are less relevant, the settings by default are respected. Below, one line for each program specifies the settings used for the radius and threshold options.

“Findglare”: radius = 1000 & threshold = Lav*7

“Evalglare”: radius = 0.1 & threshold = Lav*7 or Lav*5.

Chapter 5: Experimental studies under sunlight conditions

5.1. Multi-side-lit office

5.1.1. Introduction

First of all, it is important to describe the space where the assessments of this chapter were done. The purpose is to identify the specificity of its daylighting conditions and justify why this space is appropriate to answer some of the questions proposed by the thesis. The space belongs to the School of Architecture and Built Environment (SABE) of the University of Westminster. The location of the building is 35 Marylebone road, which goes from west to east and vice versa. The shape of the building is lengthened, with its main façade facing to Marylebone road and, therefore, north. Its back façade is then facing south.

The space, where the assessments were done, occupies the top floor of the building. The height of the surrounding buildings is mainly lower. Only an isolated tower (dwellings and hall of residence) exceeds its height. As a consequence, the space has a very high potential in terms of daylight availability. The space was designed to maximize this potential, probably thinking in the original requirements of the room. Apparently, the space was designed to teach drawing at the school of architecture. Figure 5-1 describes the plan and section of the room.

The design proposes small windows that go all over the length of the façades. They suggest the "fenêtre en longueur”, which was one of the five principles of Le Corbusier when he described the main features of his modern architecture. The window which faces north offers a horizontal landscape with Regents Park at the foreground. On the opposite side, the window which faces south shows a landscape of the roofs of Marylebone and some of the most iconic buildings of London, emerging in the distance.

Both views are only possible when the user stands up. Possibly, the architect's design considered the position of the students, time ago, when they used to work on drawing boards, standing up or sitting on a stool, in a higher position than on a chair.

The roof's shape corresponds perfectly to those spaces which were designed to satisfy tasks requiring a high performance in terms of lighting. It is a saw-tooth roof which provides overhead daylight. As usual, the serrated profile incorporates windows in the steeper side, which face north looking for diffuse light and avoiding direct sunlight reflected on the desks.

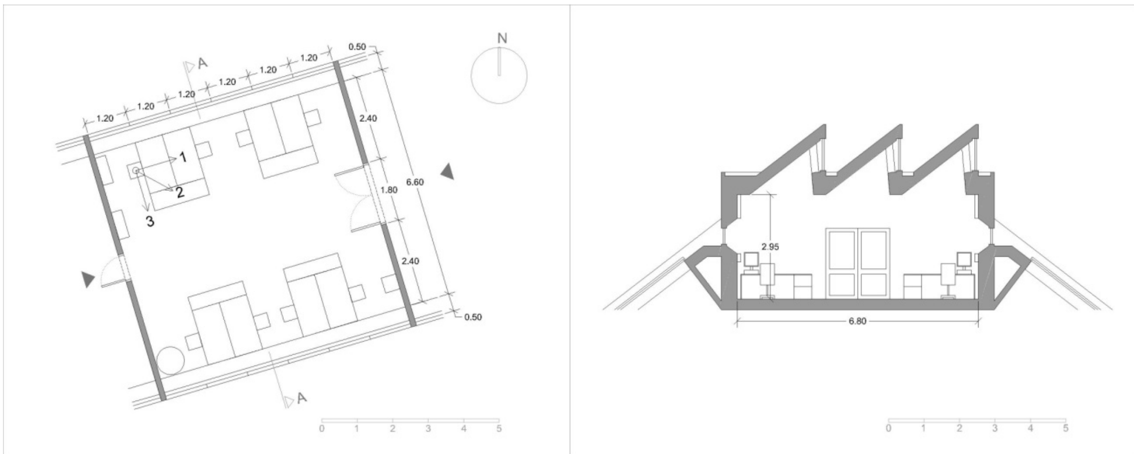


figure 5-1: London, SABE, University of Westminster, 6th floor, room M612

Currently, the room is no longer used to teach how to draw by hand. The space belongs to the Research Group of SABE and mainly accommodates PhD students. Their tasks require common tables with desktop computers, as it happens in an office room. Therefore, this space is useful to do the assessments, considering it as an office space lit by specific lighting conditions, which are convenient to get the answers to the key questions that this chapter proposes.

The room allocates eight desks, providing them with spaciousness. The position of the desks, in parallel to the windows, complies with the recommendations of the daylighting guides. If the size of the space is compared to other common offices, it could be considered medium-sized. This size permits to assess the visual comfort with a certain level of complexity. The risk of glare, which corresponds to different visual fields, can be analysed. The majority of these visual fields (watching the computer screen and others) imply a horizontal field of vision and, in different degrees, a global view of the space. They include the view of the interior and the view through the windows.

Considering these conditions, the glare effects of the sun patches and the sky portions can be compared. As it was mentioned before, the location of the room, at the top of a building, without other taller buildings in the surroundings (excepting a tower), motivates a particular view. Sitting on their chairs, the users mainly see portions of sky through the window. This specific situation permits to test if the users are equally sensitive to the glare caused by the presence of the sun patches and the portions of sky. A priori, both surfaces should be the cause of equivalent reactions because they are similar sources of brightness, which contain low levels of information (or interest). That is to say, both are plain patches, if their variations in colour or luminance are considered. Accordingly, the users' reactions should be similar. By means of questionnaires, this assumption is tested in the next chapter. The experiments are done when the sunlight conditions are not extreme (DGI under 20). These are the most critical conditions, when it is no so obvious to affirm whether a visual field is glaring or not. Beyond checking if the user's judgement agrees with calculated DGI and DGP indexes, the aim of the chapter 5.1.2 is to determine if the users give a special relevance to the sun patches. In other words, the aim is to check if the users consider that the sun patches are more glaring than the portions of sky.

Beyond checking if there is any subjective reaction of the users in relation to the sun patches, the chapter is useful to compare objectively the glaring effects of the sun patches and the portions of sky. While doing the tests, the systematic measurements (with HDR techniques and with the luminance meter) permit to verify if the luminances of the sun patches are higher than the luminances of the portions of sky. This objective verification is also done when the sunlight conditions are extreme, because the sun's position is close to one of the viewed portions of sky and, in addition, provokes specular reflections on certain materials (chapter 5.1.3). Equally, a third situation, with a high number of sun patches but with low levels of luminance, is checked. It happens when the sun patches are reflected on the ceilings. These conditions are named as "apparently extreme conditions". The chapter 5.1.4 analyses them. All the latter chapters pay attention to the results of the DGI and DGP indexes, in order to verify the consistency of their results.

5.1.2. Non-extreme sunlight conditions

The previous introduction has been useful to describe the space where the experiments of this chapter and the next two took place. The current chapter is the most relevant of the three. Besides the measurements, it includes the assessments of the users' reactions by means of their answers to a questionnaire. The first purpose of the next paragraphs is to describe the experimental process, pointing the most relevant aspects.

As the aim of the thesis is the assessment of the glaring effects of the sun patches, sunny days with clear skies were required for the experiment. Moreover, sitting in the same position, the user was subjected to the daylight conditions, and then, he was asked to answer to the questionnaire. Subsequently, the measurements related to the users' perception were done. Therefore, it was necessary the presence of totally clear skies, in order to guarantee the same daylighting conditions despite the lapse of time between the users' assessments and the measurements.

The experiment began with the subject sitting down (see the precise position on figure 5-2) and answering to the first part of the questionnaire, related to personal data and skills (figure 5-3: gender, age, glasses or contact lenses, sensitivity to light). During this time, the user was adapting to the daylight conditions and the simulation of a working attitude before starting the experiment.

Subsequently, it was possible to start the experiment under the desired sunlight conditions. The subject was exposed to these lighting conditions during one minute. Meanwhile, it was pretended to simulate a normal work activity, without focusing his attention on the lighting. The subject was asked to read a poem presented on the screen. At the same time, he was asked to look occasionally to a luxmeter, which was superposed on the screen (figure 5-4), and identify the highest and lowest values of the horizontal illuminance on that position. The purpose of the two activities was, on one hand to offer something distracting for any kind of subject (literary or mathematical minds) and, on the other hand, to privilege a horizontal sight, avoiding the sight on the table. In addition, it was said to the subject to relax his vision occasionally, looking freely the surroundings, the interior or the view through the window.

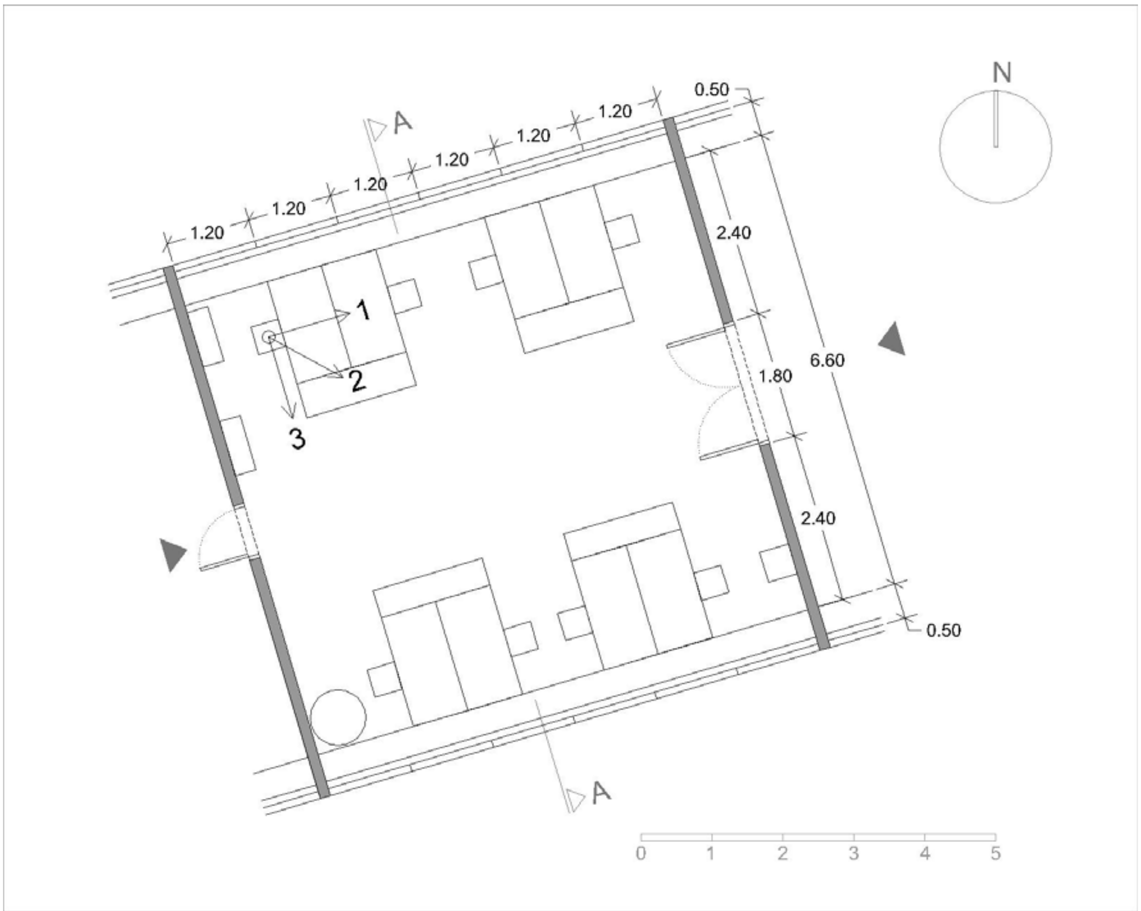


figure 5-2: Room M612, users' position and the three visual fields (VF) of the experiment 1

Immediately after one minute, the subject was requested to write the two illuminance values (highest and lowest) on a side of the questionnaire, and then, reply to the second part the questionnaire, the one referring to the assessment of the lighting conditions (figure 5-3). The two illuminance values were also useful to determine the constancy of the daylight conditions.

The two first questions of the questionnaire focus the attention on the sun patches, in a general way. The first question asks about the reaction in relation to the sun patches. The subject replies using a scale of seven degrees going from “very annoying” to “very pleasurable”. It is pretended to identify if in that situation, and by extension in any other similar lighting situation, there is any predisposition or prejudice of the subject in relation to the presence of the sun patches inside the space. The subject is forced to a subjective answer, in relation to an idea of the aesthetic pleasure proportioned by the sun patches. Conceptually, this question is close to other questions asked by other researchers on their questionnaires who tried to clarify the relation between glare and the interest of the view through the window (Tuaycharoen & Tregenza, 2005, 2007).

The second question asks to the subject to describe how difficult it is to work while the sun patches are inside the space. He can answer using a scale of five degrees, which goes from “very difficult” to “very easy”. This question is related to the previous question, as it verifies if the reaction, in terms of personal aesthetic judgement, has an influence in the degree of comfort of the users when there are sun patches in the scene. In order to avoid a direct transfer when answering these two last questions, the scale to assess the comfort has changed from seven to five degrees. It introduces the difference and suggests resuming the discussion from the beginning.

The three next questions face directly the glare issue. The three are formulated in the same way although each one of them focuses the attention on a different aspect. The two first questions are useful to compare the degree of glare caused by the view through the window and by the sun patches. This is one of the most relevant matters of this research; it was introduced before, in the introductory chapter. The third question focuses the degree of glare considering the overall scene. It is useful to find the relation between the two previous aspects (vision of the sun patches and through the window) and the overall perception. The aim is to elucidate if any of those two aspects has more weight in the perception of glare.

Name:	Surname:	Office:
Number:	Hour:	Date:

1. Gender:				
Female		Male		
2. When doing office work, do you wear glasses or contact lenses:				
Yes, glasses	Yes, contact lenses	No		
3. In case of wearing them, is it for:				
Reading		Long sight		
4. Age:				
Under 25	25-35	36-45	46-55	Over 55
5. Do you consider yourself as sensitive to light:				
Much lower than normal	Slightly lower than normal	Normal	Slightly higher than normal	Much higher than normal

ASSESSMENT RELATED TO A PARTICULAR MOMENT WITH SPECIAL DAYLIGHTING CONDITIONS (SUN PATCHES INSIDE THE ROOM)

Please, read the proposed text on your screen during 1 minute. Sometimes, relax your vision with some views of your surroundings (inside space and view through the window). Then, answer the next questionnaire.

6. Do you consider the sun patches were:						
Very Annoying	Annoying	Slightly Annoying	Neither Annoying or Pleasurable	Slightly Pleasurable	Pleasurable	Very Pleasurable

7. Please, describe the difficulty of working while the sun patches are in the space				
Very Difficult	Difficult	Neither Difficult or Easy	Easy	Very Easy
8. The degree of glare you experienced from the sun patches was:				
Just Intolerable	Just uncomfortable	Borderline between Comfort and Discomfort	Just Acceptable	Just (Im)perceptible
9. The degree of glare you experienced from the windows was:				
Just Intolerable	Just Uncomfortable	Borderline between comfort and discomfort	Just Acceptable	Just (Im)perceptible
10. The degree of glare you experienced from the overall scene was:				
Just Intolerable	Just Uncomfortable	Borderline between comfort and discomfort	Just Acceptable	Just (Im)perceptible

figure 5-3: Observer’s instruction and assessment sheet

As soon as the subject finishes answering the questionnaire, it is time to proceed with the measurements, trying to minimize the delay. The lens of the camera is installed in the same position of the subject's eyes. The previous chapter advanced that the space, thanks to its dimensions, is convenient to assess the complexity of the vision in an office space. While the subject works, three characteristic visual fields occur frequently. The first visual field (figure 5-4) is related to the most frequent work, watching the screen. The second visual field (figure 5-5), which is less frequent, happens for example when the user looks to another colleague and has a more complete view of the interior. The third visual field (figure 5-6) satisfies the need of relaxing the view looking outside. The three visual fields are susceptible to be assessed in terms of glare. For any of them, besides taking the sequences of pictures to obtain the HDR images and calculate the glare indexes, the vertical illuminance on the lens and the luminance of the central point of a grey card are measured (figures 5-4 to 5-6). They are useful to validate the calibration techniques which are explained in the methodological chapter.

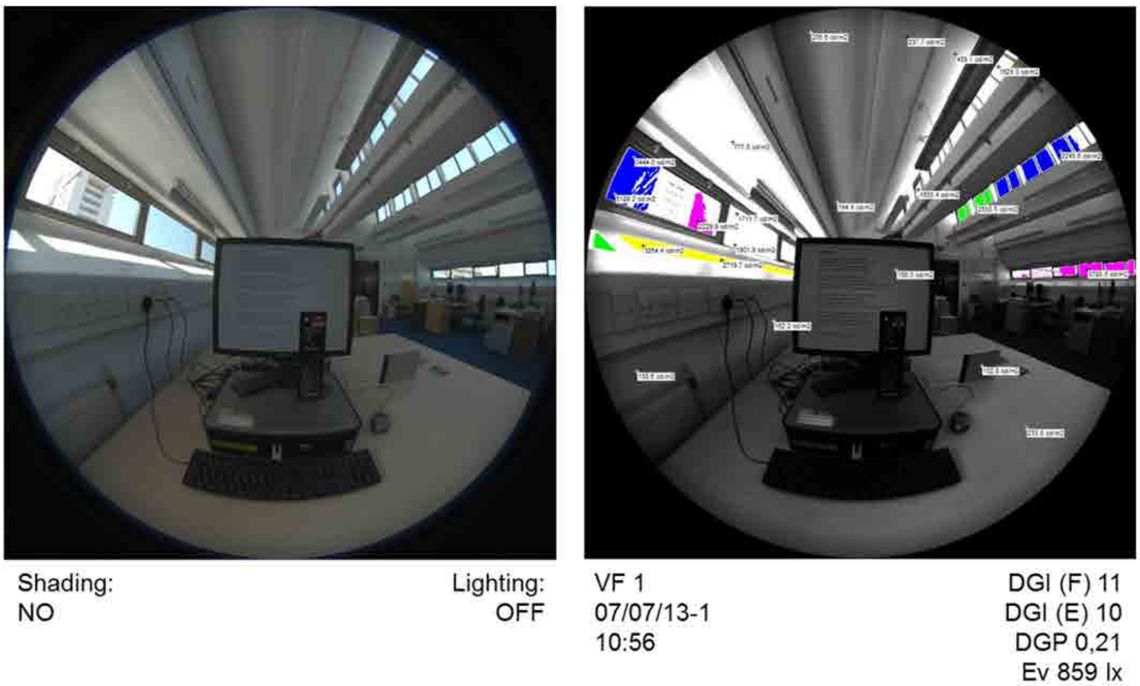
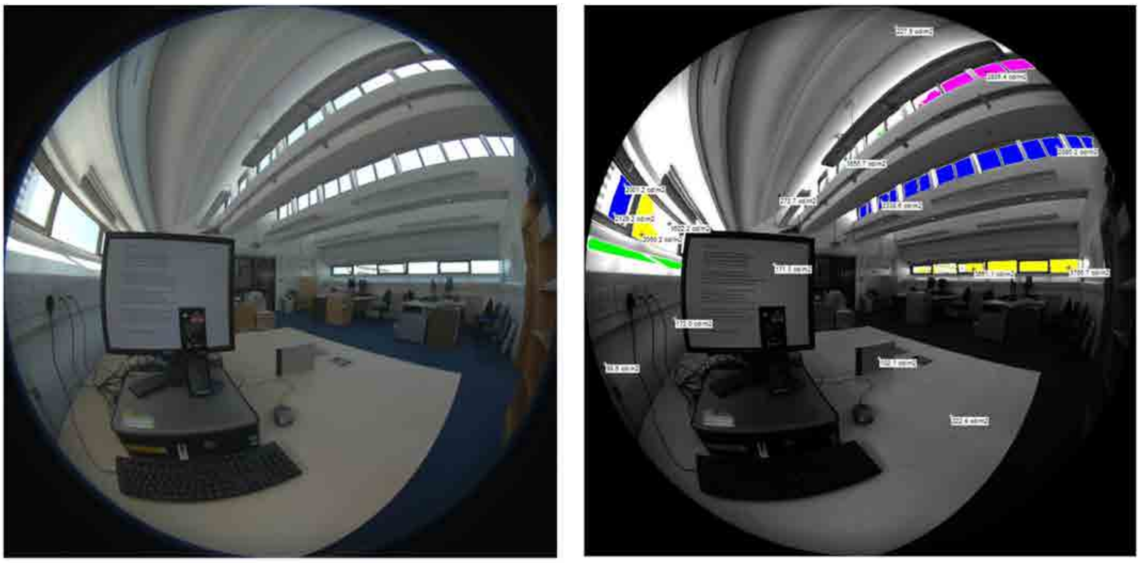
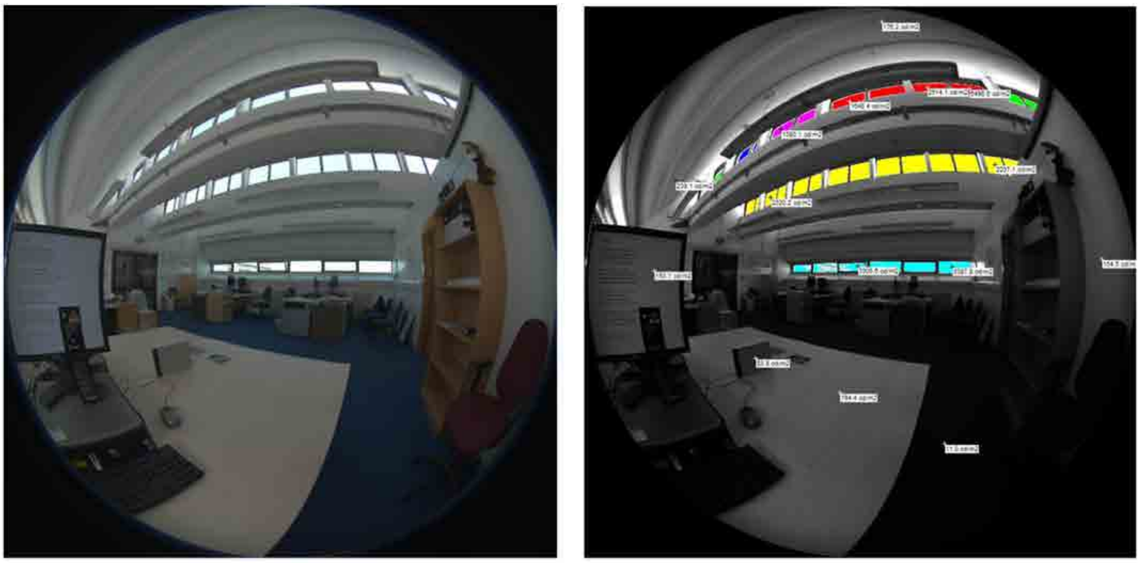


figure 5-4: VF 1(experiment 1): HDR (left) and Evalglare (right) images related to the relevant data



Shading:	Lighting:	VF 1	DGI (F) 16
NO	OFF	07/07/13-1	DGI (E) 14
		10:56	DGP 0,22
			Ev 754 lx

figure 5-5: VF 2 (experiment 1): HDR (left) and Evalglare (right) images related to the relevant data



Shading:	Lighting:	VF 1	DGI (F) 20
NO	OFF	07/07/13-1	DGI (E) 19
		10:56	DGP 0,24
			Ev 764 lx

figure 5-6: VF 3 (experiment 1): HDR (left) and Evalglare (right) images related to the relevant data

Eleven subjects were selected for the study. The graphs of Figure 5-7 describe the personal characteristics of these subjects. All of them have a personal relation with the School of Architecture and Build Environment (SABE). Most of them are students of the university and the majority develop their research degree. This reason explains the youth of the subjects. Their ages are mainly between 25 and 35 years old. Their youth can be understood as one of the reasons of their good vision, as only two of them wear glasses or contact lenses. In addition, perhaps because a great number is related with the studies of architecture, they consider that their sensitivity to light is normal or even slightly higher than normal. Despite that, they are far of being considered as “human meters” as Hopkinson and Bradley (1960) did when they named the subjects of their experiments, who received special training before the assessments in order to improve their sensitivity to light. Nonetheless, beyond the personal characteristics that appear in the questionnaire, before the assessments, the informal conversations permitted to ask the subjects about two relevant aspects to obtain information about their personal background in relation to daylight.

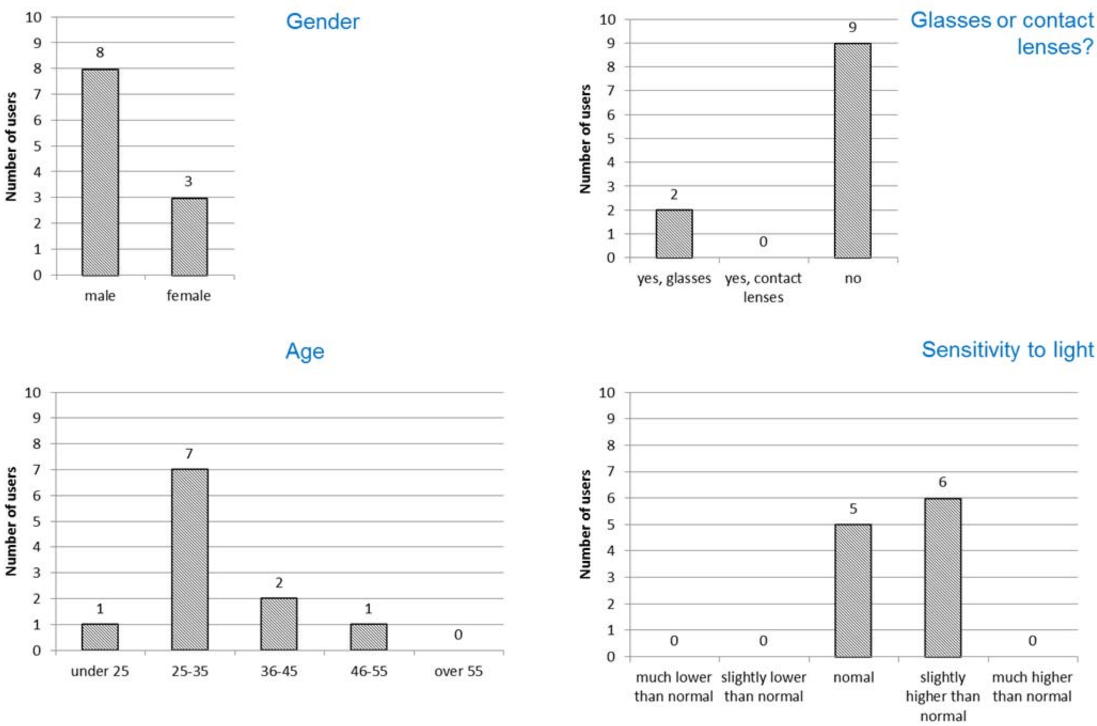


figure 5-7: Gender, age, eyesight and sensitivity to light of the observers

The first aspect pretended to identify if the users, in their normal life, are mainly used to work under daylight or artificial light conditions. Three subjects (figure 5-8: subjects 2, 8 and 9) are members of the Research Group of SABE and work in the space where the assessments took place, although none of them works normally on that precise desk. Three other subjects (figure 5-8: subjects 1, 10 and 11) are also members of the Research Group and work in contiguous spaces, which are almost identical repetitions of that space. Considering the characteristics of the space, which have been extensively described previously, it is appropriate to say that these six subjects are used to work under daylight conditions. The remaining subjects do their work in other spaces of the same building. All of them work in side-daylit spaces except one subject (figure 5-8: subject 5) who is a member of the security staff and normally works in an artificial lit space, watching the security monitors.

The nationality is the second aspect which gives information about the daylight background of the subjects. The nationality was rigorously written on the printed page of the questionnaire and appears in figure 5-8, associated to the answers of the subjects.

The superior part of that figure presents in a grey scale the results of the DGI calculations. Three vertical bars show the results of the three visual fields. The light grey bar corresponds to the first visual field (figure 5-4), the medium grey corresponds to the second visual field (figure 5-5) and, finally, the dark grey bar corresponds to the third visual field (figure 5-6). The vertical lines (black dots) separate the results corresponding to each one of the eleven users. The horizontal lines (blue dashed) depict the index values which are associated to different degrees of glare: “perceptible” if the result exceeds 18 and “disturbing” if it exceeds 24. Analysing the results, three first remarks are consistent. First, there is a remarkable constancy in the results, even if the assessments took place in slightly different days and hours. Approximately, the first visual field equals 10, the second 15 and the third 18. These results entail the second remark. In just four occasions, the results are equal to 19 and the glare is identified as perceptible. This situation always happens when the user is looking through the window. This fact anticipates a third relevant remark. The DGI results are clearly higher when the glare sources are close to the centre of the vision.

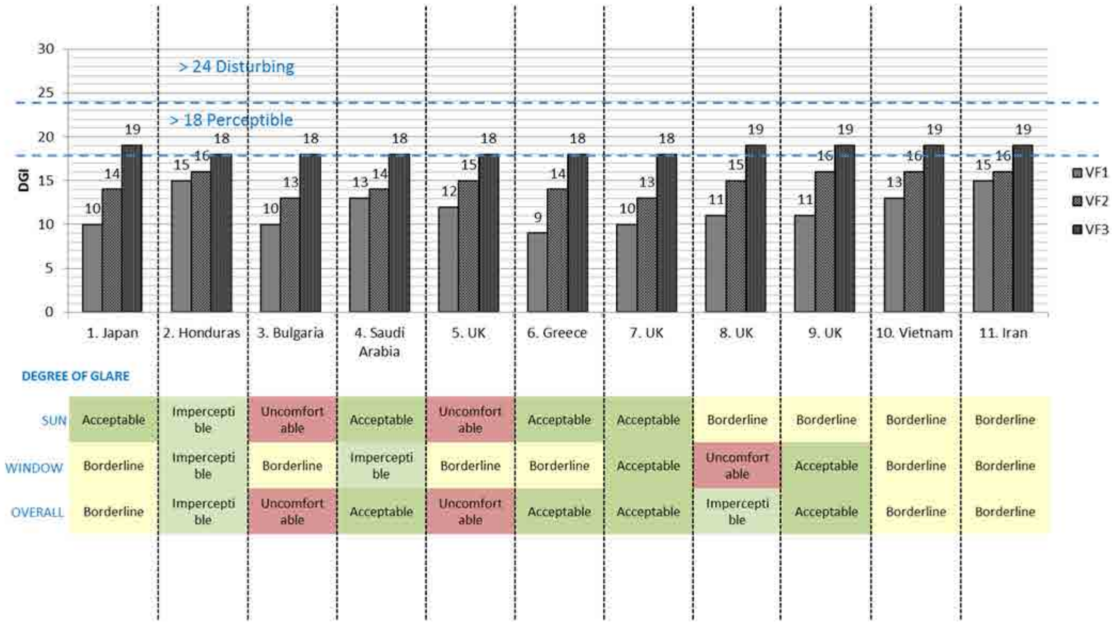


figure 5-8: Eleven users and their nationalities related to their experience of glare and the DGI results of VF 1, 2 and 3

The inferior part of the figure 5-8 represents, by means of a code of colour, the answers of the users to the three last questions of the questionnaire. Each line refers to the degree of glare perceived during the experiment. They distinguish the glare caused by the sun patches (first line), the windows (second line) and the overall scene (third line). Analysing the figure in vertical, the users' perception can be compared to the degree of glare calculated thanks to the measurements.

It is time to mention that several research works were consulted before deciding the adjectives proposed to the users to describe they degree of comfort or discomfort (Hopkinson, 1970/71, 1972; Chauvel *et al.*, 1982; Wienold, 2009b, 2010). Different scales, based on a different number of degrees of comfort and using different adjectives, have been identified. Similarly, it is not easy to find works that use precisely the same scale which is associated with the DGI values. Finally, in order to facilitate the comprehension of the users, this research decides to employ a scale based on five degrees (Tuaycharoen & Tregenza, 2007): just intolerable, just uncomfortable, borderline between comfort and discomfort, just acceptable, just (im)perceptible (figure 5-3).

On the other hand, some studies (Jakubiec & Reinhard, 2010, 2012; Suk & Shiler, 2013) simplify the DGI scale using three adjectives, which are linked to three DGI values: intolerable (DGI>31), disturbing (DGI>24), perceptible (DGI>18). It is also usual to find the grade of “imperceptible” or “barely perceptible” when DGI<18. The present research adopts this scale based on three adjectives. It is considered that it can be found an easy link with the scale of five degrees of the questionnaires. The first value (DGI>31 - intolerable) is obviously linked to the grade of “just intolerable” of the questionnaire. The next value (DGI>24 - disturbing) can be linked to the next option of the questionnaire (just uncomfortable). This option clearly denotes an idea of discomfort, although it is not an extreme degree. Finally, the last value (DGI>18 - perceptible) is the most critical. It could be linked with the three last options of the questionnaire (borderline between comfort and discomfort, just acceptable and just (im)perceptible). These options declare the presence of glare as an idea of contrast, which is perceived and tolerated because the experience is not clearly identified as uncomfortable.

After clarifying the terms to describe the degree of glare, it is possible to return to the figure 5-8 and analyse the results. Then, starting from the previous statements and avoiding the comments of particular cases, some general remarks could be accepted. Basically, there are two lines of argument that are meant to be treated thanks to the experiment. The first line argues the existing relation between the calculated glare indexes and the users’ reactions. The second line studies if, in terms of glare, there is any prejudice of the users against the sun patches.

Concerning the first line of argument, it is necessary to start emphasizing the specific conditions during the experiments. Reading the results of the DGI indexes, none of the scenes is particularly glaring. Under these circumstances, it can be said that it exist equivalence between the DGI predictions and the users’ responses. Only 5 of the 33 responses describe the reaction as uncomfortable. What is more difficult is to predict the most frequent degree of perception of the users when they describe a situation which is far of being uncomfortable. A small number of users (5) consider that glare is imperceptible and most of them debate if glare is acceptable (10) or in the borderline between comfort and discomfort (13). Perhaps, considering the relation between the DGI prediction and the users’ reaction, a comment could be added. Most of the DGI calculations are clearly under 18. In accordance, the classification is supposed to indicate that glare is barely perceptible. However, as it has been mentioned, a considerable number (13) identify the perception in the borderline between comfort and discomfort. Therefore, it could be said that the DGI glare index underestimates slightly the users' sensitivity to glare.

Concerning the second line of argument, it seems appropriate to affirm that there is not prejudice against the sun patches in terms of glare. Two main evidences support this statement. First, among the eleven subjects, only two of them identify the glare caused by the sun patches as uncomfortable. Equally, they affirm the relevance of the sun patches in the overall scene, as the degree of glare is also considered uncomfortable. One speculation could explain the reaction of one of the two subjects. He is the only one who normally works in a small room under artificial light conditions; with which, he is used to adapt his comfort to lower illuminance levels and uniform luminances. Regarding the second subject, the conversation was not sufficient to argue a reasonable speculation. The second evidence derives from comparing the answers related to degree of discomfort related to the sun patches and the view through the windows. In four occasions the degree of discomfort is worst when speaking about the sun patches. In three occasions the opposite happens and, finally, in four occasions equal reactions are avowed. In addition, when there are different reactions, the users only identify the minimum degree of difference, i.e. only one degree. According to these results, it seems proper to affirm that the users are not more sensitive to the glare caused by the sun patches.

Let us progress to the next figure 5-9 and check if it supports the same statements. That figure compares the answers to the questionnaire in percentages, by means of three graphs. On the left hand side, two graphs present the results of the two first answers of the questionnaire. Above, the vertical bars of the first graph represent the subjective reaction of the users, in relation to an idea of the aesthetic pleasure proportioned by the sun patches. Bellow, the vertical bars of the second graph describe how difficult it is to work while the sun patches are inside the space. This graph is related to the previous one, as it verifies if the reaction, in terms of personal aesthetic judgement, has an influence in the degree of comfort of the users when there are sun patches in the scene. Finally, on the right hand side, the third graph introduces the concept of degree of glare and offers a connection with the answers to the two first questions. Simultaneously, the bars represent the degree of glare experienced from the sun patches, the windows and the overall scene.

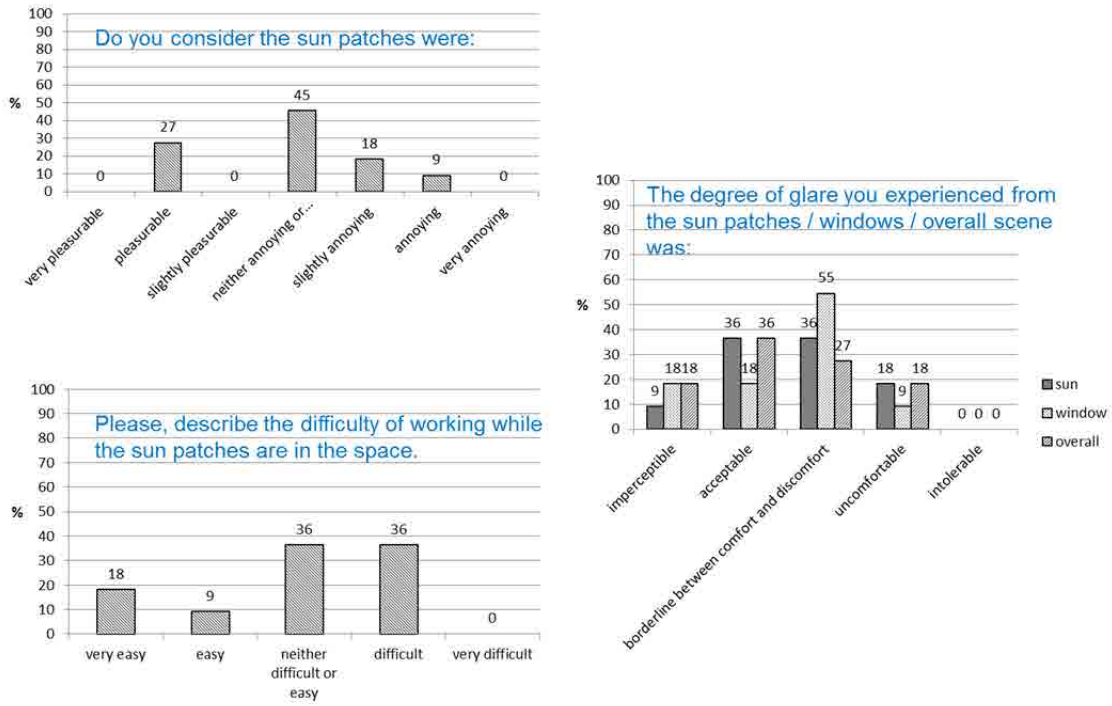


figure 5-9 Answer to the questionnaire in percentages

Looking at the first graph (top left), the 45% of the subjects do not recognise being affected by the sun patches. Apparently, the presence of the sun is not as high as to become decisive. The remaining 55% of the subjects are equally distributed according to the two opposite descriptions (pleasurable and annoying). However, the perception of a pleasurable situation seems clearer since nobody adds the adverb “slightly”. The reaction is different when the subjects identify the situation as annoying. Those who say that the situation is “annoying” are exactly a half (9%) of those who say that the situation is only “slightly annoying” (18%). Consequently, it is difficult to affirm that there is a subjective conduct which is clearly opposed to the presence of the sun patches (only the 9% of the subjects shares this judgement).

The answers, which are presented on the second graph (bottom left), show similitudes with those of the previous graph. The majority of the subjects do not adopt a positive or negative attitude in front the sun patches. Nevertheless, the percentage is now inferior (36%). Conceptually, the term difficulty can be considered as something more specific than an idea of aesthetic pleasure. This could be the reason which explains that it becomes easier for the subjects to identify their own reaction. In that graph, there is a higher proportion that describes negatively the situation. The 36% of the subjects say it is difficult to work, against the 27% which consider the opposite. Despite that, those who judge that it is difficult to work are not so emphatic. None of them says it is very difficult. In contrast, among the subjects who say it is easy to work, two thirds (18%) are definitive and say it is very easy.

The last graph (right) could be the definitive to conclude if the subjects have a prejudice against the sun patches. It represents their judgement in relation to the degree of glare. Now, the answers pretend more abstraction and the positive or negative meaning is less simple. On this occasion, a small number of users associate the degree of glare with a negative description. There is a concordance if the degrees associated to the sun patches, windows and the overall scene are compared. It is also possible to argue the agreement with the previous graphs. A great number of users describe a degree of glare in the borderline between comfort and discomfort, avoiding the positive or negative meaning. If the positive answers are analysed, it is convenient to remark that the positive assessments in relation to the sun patches are more frequent (9+36=45%) than those in relation to the windows (18+18=36%). In addition, those judgements related to the sun patches have apparently a greater influence when the degree of glare of the overall scene is described, as its total percentage is quite similar (18+36=54%).

Considering all this, it is difficult to affirm that the subjects would react negatively if there is presence of sun patches in the scene. Nonetheless, it seems that the opposite could happen because the assessments present a higher number of positive reactions.

As the answers in relation to the degrees of glare are apparently definitive, it is interesting to emphasise their relevance with a second graphical representation (figure 5-10). Now, the graphs study separately the answers to each one of the three questions. Each vertical bar represents the answer of one user. Then, there are eleven bars in each graph corresponding to the eleven subjects. The high of each bar correspond to the calculated DGI index of the most frequent visual field, i.e. watching the computer screen (VF1). A horizontal blue dashed line is added in each graph. Under that line (DGI<18), glare is imperceptible or, in other words, barely perceptible.

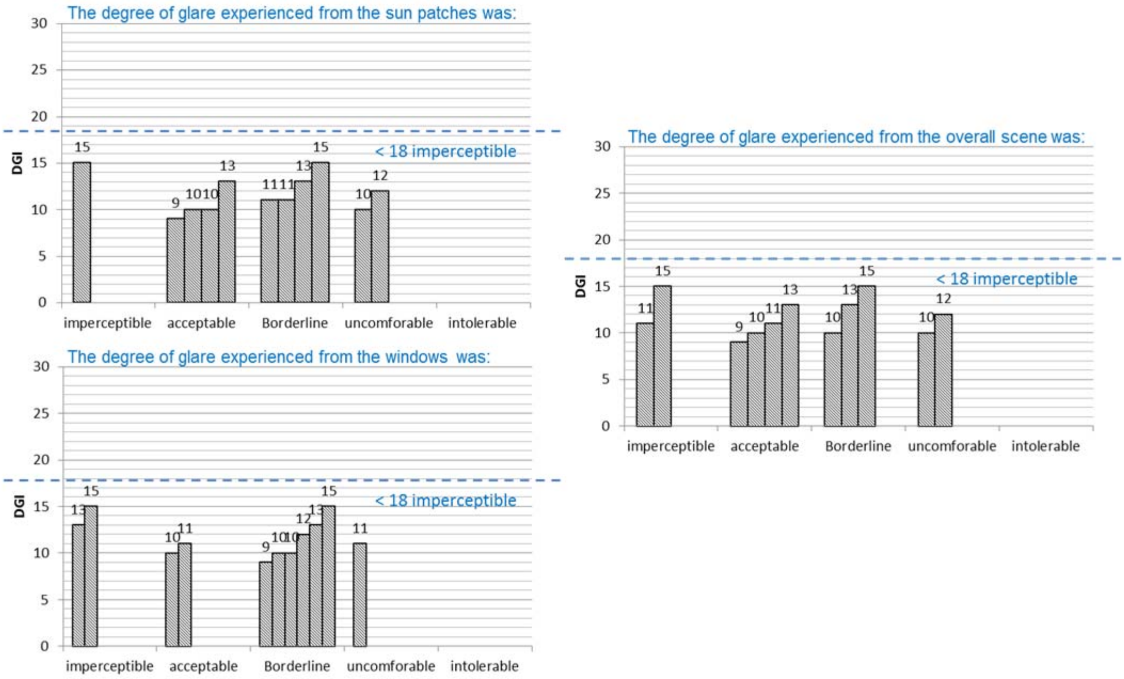


figure 5-10: Glare experienced by the users compared to the DGI results of VF 1

It is inevitable to recognise the correspondence between the first graph (top left), related to the degree of glare experienced from the sun patches, and the last graph (right), which considers the overall scene. Practically, the same distribution of bars, with the same heights (values), is distinguished. It means that many subjects reply with the same degree of glare when they consider the sun patch and the overall scene. Furthermore, it can be said that the assessments are clearly positive because only two bars appear related to a perception of uncomfortable degrees of glare.

The correspondence is lower when the degree of glare from the window (bottom left) is described. Curiously, more subjects are not able to distinguish between a positive or negative meaning. Then, they describe the degree of glare in the borderline between comfort and discomfort. Despite that, the positive meaning is again more frequent (4 bars) than the negative meaning (1 bar).

Hence, considering the visual fields and the low degrees of glare of the experiments, the analysis of the answers to the questionnaires permits to affirm the following statements:

1/ In terms of glare, there is not a specific negative reaction of the subjects when they consider the sun patches.

2/ Instead, a positive reaction can be commonly identified.

3/ As Tuaycharoen and Tregenza (2007) argue when they consider the impact of the view through the window, it could be studied how to reduce the calculated degree of glare when there are pleasant sun patches in the scene.

Further research is convenient. More tests in order to increase the number of subjects would be useful to verify the last statements. For sure, these tests would be helpful to deduce if the personal background of the subjects (their nationality and the lighting conditions of the spaces where they use to work) is conditioning their answers.

5.1.3. Extreme sunlight conditions

The previous chapter validates the calculations of the glare indexes when direct sunlight appears in the scenes. The experiments demonstrate that the sun patches do not require a special consideration. Like the portions of sky, the sun patches can be included as part of the glare sources. It has been mentioned that the results of the glare indexes could be slightly adjusted according to the degree of pleasure that they provoke. The following case studies do not pretend to add more research in relation to these adjustments. The research does not continue the work with questionnaires; it accepts the existing glare indexes, even if they could be slightly improved, and centres the attention in the description of the daylight balance considering significant variables during sunny days.

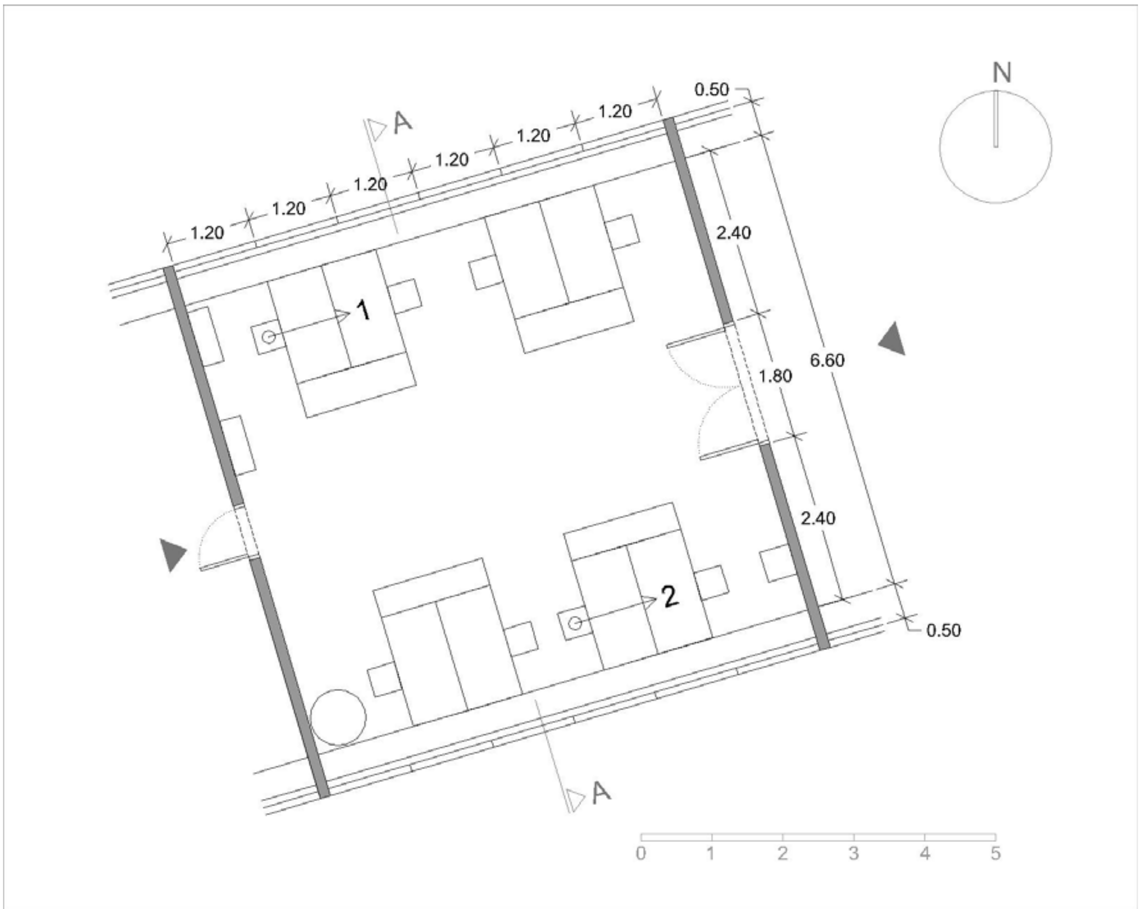


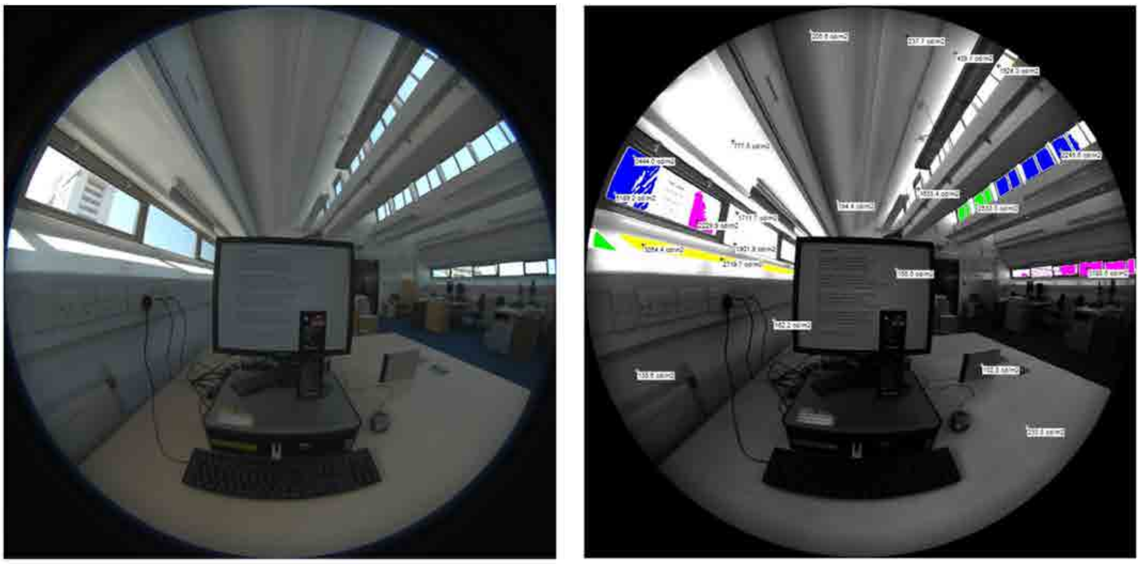
figure 5-11: Room M612 and two VF (experiment 2): comparison of the glare effects depending on the sun’s position

All the next experiments will be based on the comparison of the calculated glare indexes corresponding to different visual fields in interior spaces. Specifically, the present chapter continues with the assessments inside the space which had been described in the previous chapter. The visual field, which was related to a working task watching a computer's screen, is now compared to the same task but sitting in another desk (figure 5-11). In addition, the sun's position is substantially different. The previous visual field considered a position of the sun in the back of the observer, corresponding to the morning hours (figure 5-12). The new visual field looks for the opposite conditions, which are more extreme, with the sun facing the observer, close to the sunset hours (figure 5-13). Consequently, the luminances are notably higher. The aim is to identify the particularities of the scenes in which the calculated glare indexes describe uncomfortable situations.

Below the pictures, the figures 5-12 and 5-13 present (on the left) additional information that describes the settings of the lighting controls. "Shading: NO" means that the roller screens are not used and the view through the window is totally permitted (for both scenes). "Lighting: OFF" clarifies that the artificial lighting is turned off in both scenes. On the right side, DGI (F) corresponds to the DGI calculated by Finglare. DGI (E) is the same index but calculated by Evalglare. This last program also calculates DGP. Finally, the last value (Ev) corresponds to the vertical illuminance on the lens.

The next figure 5-14 shows an enlargement of the Evalglare images which depict the glare sources with colours. The purpose is to make easier the reading of the luminance values. Then, it is possible to check the differences between the luminances of the sun patches and sky's portions of the two visual fields.

Figure 5-15 summarizes all the graphs comparing the data of the two visual fields. At the bottom, three graphs present, from left to right, the DGI, DGP (calculated by Evalglare) and Ev. Above, three graphs add three other parameters which are relevant to interpret the results (Ls, Lb and Lav). For the time being, the calculations continue to be repeated twice using two thresholds. This strategy is useful to continue testing the influence of the thresholds on the results. Two vertical grey bars are used to describe both results: light grey for Lav>7 and dark grey for Lav>5. Logically, all the results are different, except Lav and Ev.

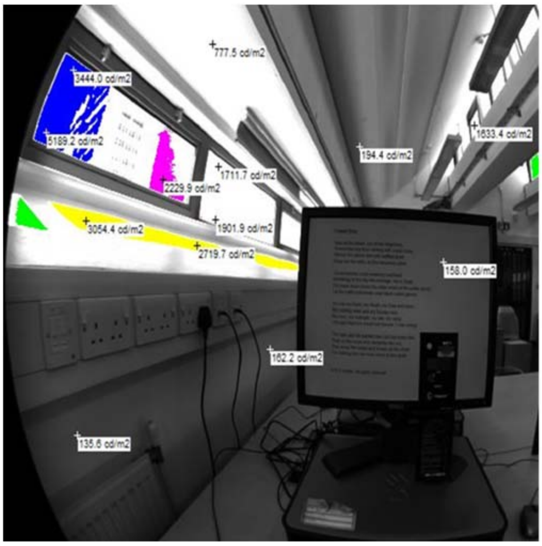


Shading: NO
Lighting: OFF
VF 1
07/07/13-1
10:56
DGI (F) 11
DGI (E) 10
DGP 0,21
Ev 859 lx

figure 5-12: VF 1 (experiment 2): HDR (left) and Evalglare (right) images related to the relevant data

Shading: NO
Lighting: OFF
VF 1a
11/07/13
18:43
DGI (F) 25
DGI (E) 25
DGP 0,32
Ev 1749 lx

figure 5-13: VF 2 (experiment 2): HDR (left) and Evalglare (right) images related to the relevant data



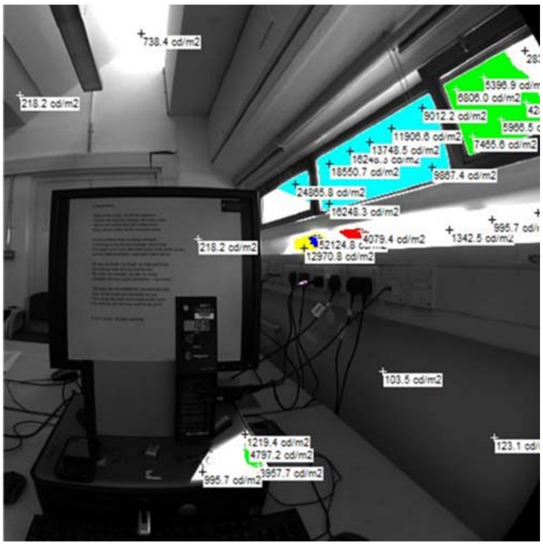


figure 5-14: Detail of the luminance values of VF1 and VF2 (experiment 2)

The DGI results are extremely different if we compare VF1 and VF2. A difference of 12-15 units is really significant given that the DGI formulation establishes the relation between Ls and Lb using a logarithmic formulation. Besides, if the results are related to the scale of perception (blue horizontal lines), it is proper to affirm that if a user perceives the first visual fields (VF1), he will not experience glare. However, if the same speculation is done in relation to the second visual field (VF2), he will start to be disturbed, although the situation is far from being intolerable.

The DGP results do not describe the same hypothetical reactions of the users. If we compare VF1 and VF2, the numerical difference is less relevant. The DGP result for VF2 does not duplicate the result for VF1. But, what is more significant, both results are under the blue line which identifies a perceptible degree of glare. Again, it is convenient to mention the mathematical formulation to interpret the results. The DGP index is based on the addition of a first term - where Ev is the relevant factor - and a second term which is equivalent to the DGI expression - where Ls and Lb are compared using a logarithmic expression. According to that, Ev acquires more relevance but, apparently, the values corresponding to VF1 and VF2 are not as high as to describe a “perceptible” glare and cause a significant difference between the two visual fields. Although the DGP index has been validated specifically for very bright scenes (Wienold & Christoffersen, 2006), it seems to denote a lack of sensitivity.

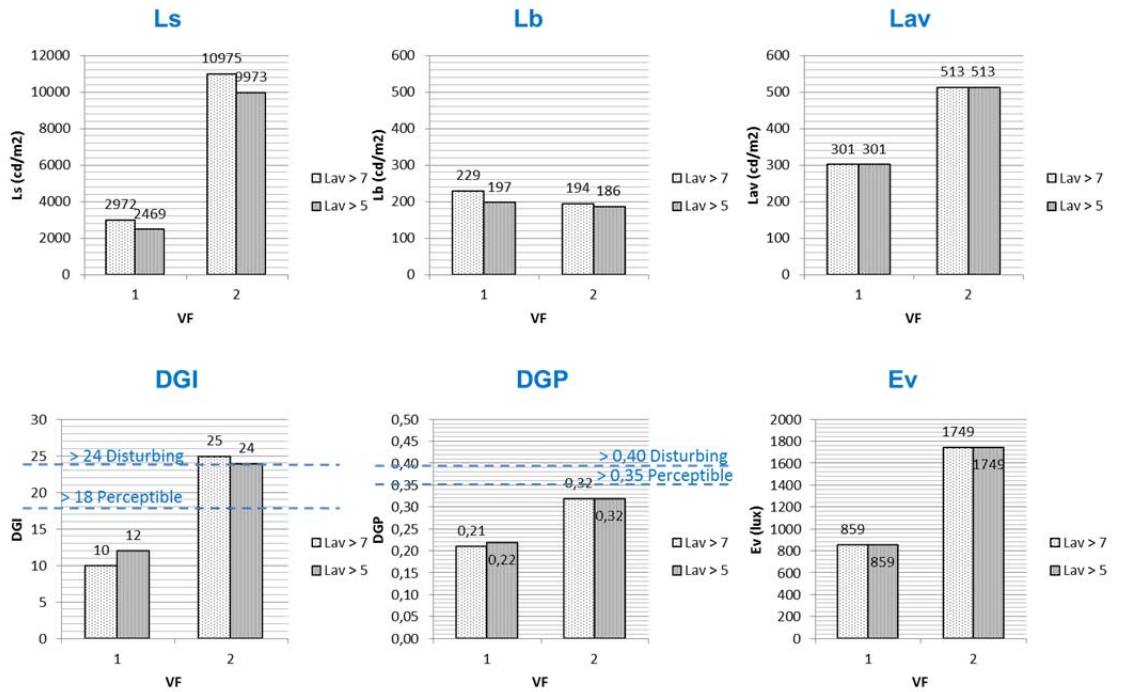


figure 5-15: Results experiment 2: Ls, Lb, Lav, DGI, DGP and Ev of VF1 and VF2 using two different thresholds (Lav>7 and Lav>5)

The analysis of the results of Ls, Lb, Lav and Ev is necessary to understand the results of the DGI and DGP indexes. Even if VF1 and VF2 are apparently equivalent in terms of size and position of the glare sources, as well as in terms of background luminance, it necessary to go through the calculated values. Lb is, indeed, almost equal for both visual fields. The values are quite high because, as it has been described previously, it is a multi-side daylit space. Despite that, the present comparison of visual fields reveals a very large difference in the values of Ls. The value corresponding to VF2 is 4 times higher than the value related to VF1. The combined effects of the two previous factors (Lb and Ls) imply that the Lav and Ev values of VF1 approximately duplicate the values corresponding to VF2.

In order to be more precise in the analysis, it is convenient to go over the luminance values, pixel by pixel, of the glare sources that are visible in the enlarged picture of figure 5-14.

As first category of glare sources, the luminance values of the sky need to be analysed. In VF1, the maximum luminance values of the sky (5200 cd/m2) are related to the horizon. In VF2, they are approximately 5 times higher (25000 cd/m2) and their position surrounds the sun's halo. In opposition, the difference is lower if the minimum luminance values of the sky, which belong to the glare sources, are compared. In VF1 they are located in the closest positions to the zenith (3400 cd/m2) and in VF2 their position correspond to the farthest in relation to the sun's halo (5400 cd/m2). Then, in VF2 they are 1.5 times higher than in VF1.

As second category of glare sources, the luminances of the sun patches require the same comparison. In VF1, the maximum luminance values are found reflected on the white varnished painting (3200-2700 cd/m2). In VF2, on the same white varnished painting a wide range of luminance values can be read (52000-4000 cd/m2). The range is lower when the sun is reflected on the dark pc-case (4800-4000 cd/m2). Consequently, the luminance values of the sun patches in VF2 oscillate between 17 and 4 times higher than in VF1.

In conclusion, the detailed reading of the luminance values emphasizes the relevance of two factors: the sun's position and the type of reflection on the interior surfaces. It must be said that, although the studied situation is one of the worst possible (sun's position in front the observer) the glare effects are just disturbing (DGI equal to 24 or 25, just above 24) and far from being intolerable (above 31). From these positions that face the sunbeams, the specular reflections on the interior surfaces (white varnished painting) are critical and aggravate notably the risk of glare.

A secondary conclusion concerns the slightly different results using the two different thresholds to define the glare sources. Their repercussion can be considered irrelevant in the final results.

5.1.4. Sun patches on ceilings

The previous chapter identifies a highest risk of glare in specific sunlight conditions, at the sunset, when the sun's halo is visible through the window and provokes bright reflections on the surfaces (varnished and white painting). The current chapter analyses the same interior under similar sunlight conditions (similar day and hour). It adds to the study other positions and sights that are interesting to understand the glare effects when numerous sun patches are visible in the interior.

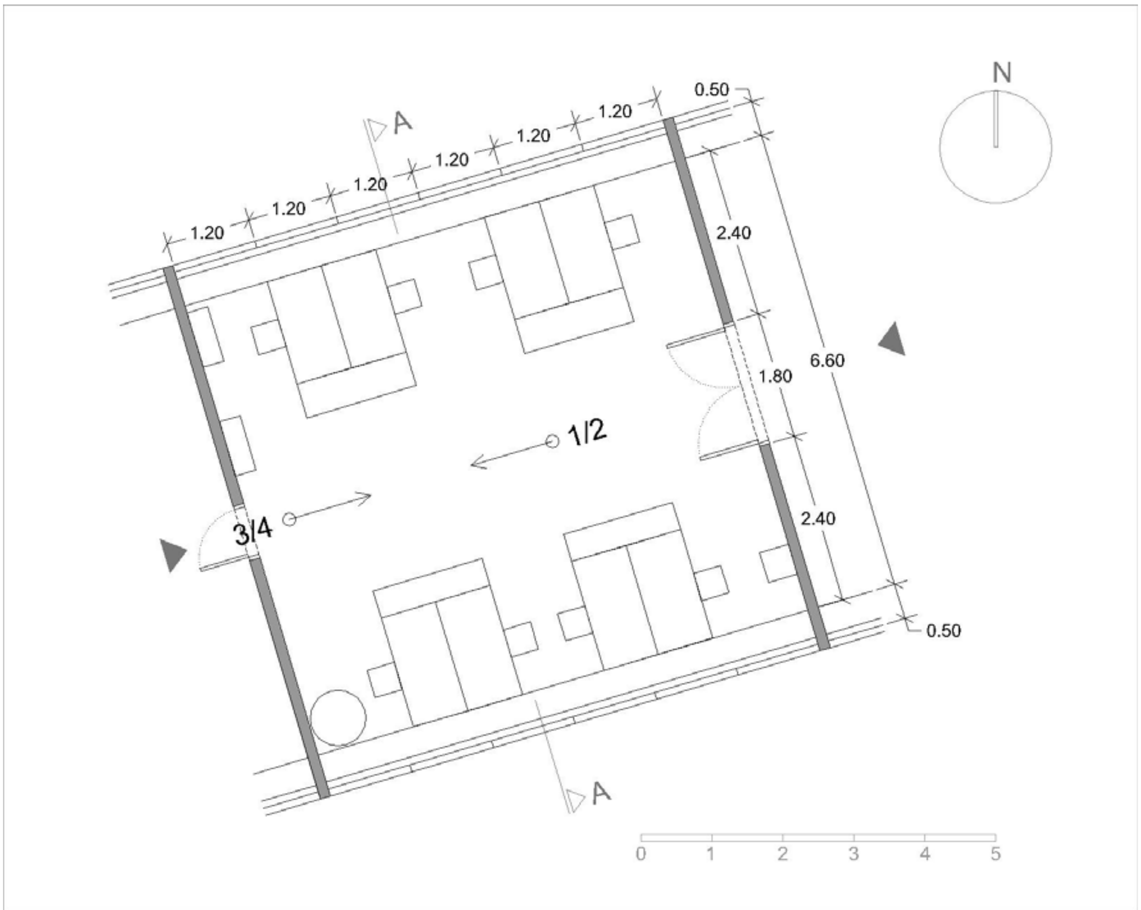
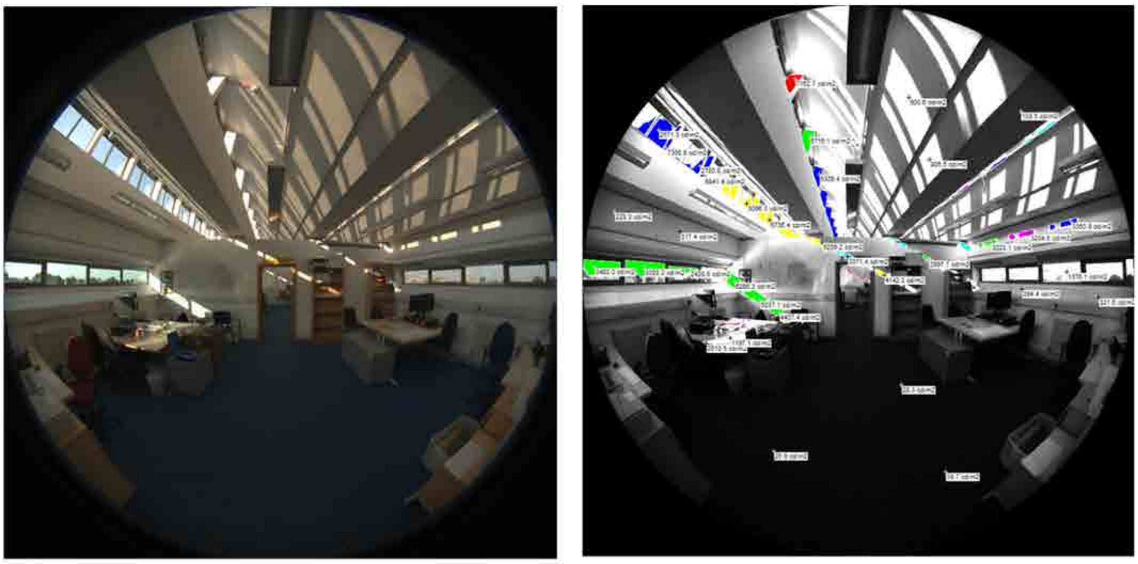


figure 5-16: Room M612 and four VF (experiment 3): comparison of the glare effects caused by sunlit ceilings



Shading: NO	Lighting: OFF	VF 1a 13/07/13 19:20	DGI (F) 15 DGI (E) 17 DGP 0,24 Ev 1157 lx

figure 5-17: VF 1 (experiment 3): HDR (left) and Evalglare (right) images related to the relevant data

Shading: NO	Lighting: OFF	VF 3a 13/07/13 19:20	DGI (F) 22 DGI (E) 22 DGP 0,29 Ev 1466 lx

figure 5-18: VF 3 (experiment 3): HDR (left) and Evalglare (right) images related to the relevant data

Two visual fields are analysed (figure 5-16). They correspond to the sight of a user who would stand up in the circulation space. In that situation, he would have a general and fleeting appraisal of the interior that could also motivate his decision of modifying the lighting conditions. More precisely, each one of the two visual fields is duplicated with two HDR images that were created using two different sequences of images with different centres of bracketing. The first visual field is identified with two acronyms (VF1 and VF2), one for each centre of bracketing. Figure 5-17 presents VF1. Similarly, the second visual is associated to two other acronyms (VF3 and VF4). Figure 5-18 shows VF3. Both visual fields present numerous sun patches which are reflected on the distinctive shape of the ceiling. The purpose of this third experiment in the same space is to verify the corresponding results of the glare calculations under these particular sunlight conditions. Are the scenes as glaring as they seem to be due to the numerous sun patches?

The graphs presented on figure 5-19 offer an answer to the previous question. At the bottom, two graphs present the results of the glare indexes (DGI and DGP). At the top, two graphs indicate the values of Ev and Lb. As in the previous chapter, in order to continue checking the influence of the calculation methods, the calculations are repeated twice, using two different thresholds (Lav>7 and Lav>5) to define the pixels included in the glare sources. Moreover, the graphs specify the results according to the two HDR images of each visual field (1, 2 = VF 1 and 3, 4 = VF2).

As in the previous chapter, the results demonstrate the decisive influence of the sun's position in relation to the observer. If the results of the two visual fields are compared, the calculations show that the DGI index is 5 units superior when the sun is facing the observer. In terms of perceived degree of glare, the situation changes from barely perceptible (sun at the back) to perceptible (sun at the front). Even so, the result remains under the degree which describes the situation as disturbing. Then, it is supposed that the user would not change the lighting conditions of the interior.

The previous chapter explains how Ev and Lb condition the DGI results. Again, the analysis of these two factors is the key to understand the results. All the visual fields have similar Lb but, when the sun faces the user, Ev is higher. Consequently, we can deduce that Ls is higher. Although in this third experiment, Ls is not so high compared to Lb. That is why the calculated degree of glare does not exceed the value that describes a disturbing situation.

The DGP results are questionable again. Obviously, when the sun faces the observer, the DGP result is higher (DPG = 0.29). Even so, this result is far from the DGP degree that describes glare as perceptible (DGP = 0.35). Again, the Ev values condition the DGP results. They are slightly higher for VF3 and VF4 but the still remain under the levels that cause a perceptible glare according to DGP.

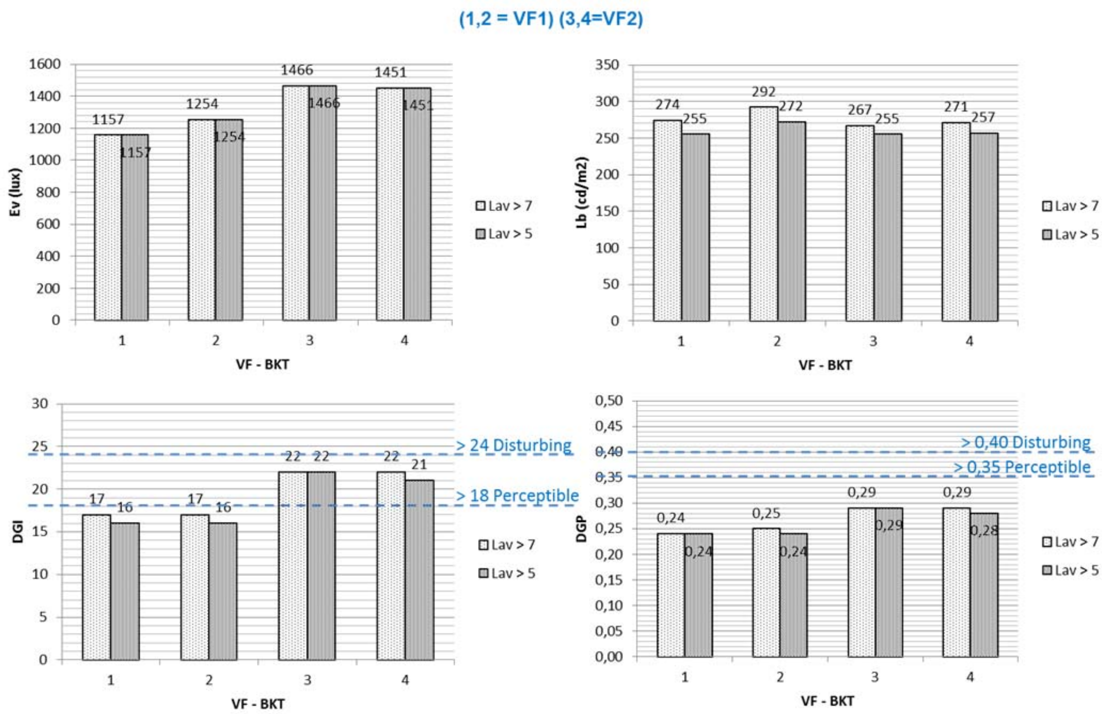


figure 5-19: Results experiment 3: Ev, Lb, DGI and DGP and Ev of VF 1, 2, 3 and 4, using two different thresholds (Lav>7 and Lav>5)

In conclusion, this last experiment insists in the repercussions of the sun's position (in relation to the observer) for the calculations of the degree of glare. Equally, the experiment proves that, if the luminance of the background is high, it is quite difficult to experiment a perception of glare. Unlike what could be foreseen, it is shown that lots of sun patches in a scene do not necessarily imply high levels of glare. In accordance with the particularities of that experiment, the luminance levels of the sun patches are not as high as it could be expected. There are two possible reasons. Firstly, the sun beams, when the elevation of the sun is low, cross wide layers of atmosphere and are less powerful. Secondly, the reflections on the surfaces are quite sloping and imply lower levels of illuminance on the surfaces, and then, lower levels of luminance of these surfaces. Due to the low luminance levels of sun patches, most of them do not exceed the threshold to be considered as glare source. Contrarily, they are included as pixels of the background, increasing the value of Lb, and then, provoking low degrees of glare.

The aspects concerning the different settings of the methods and their repercussions on the results, even if they are secondary aspects, deserve to be mentioned. Firstly, the impact of the definition of glare source is very low. The two typical thresholds (Lav > 7 and Lav > 5) provoke similar results. The DGI results do not change, or they change only one unit. Exactly the same happens to the DGP results. In accordance, the luminance of the background is not suffering big differences. This fact was proved in the previous chapter and it has been verified with this third experiment. Secondly, the effects of the two different centres of bracketing are also contemptible. Even if they cause small changes in the results of Ev and Lb, they do not have repercussions on the degrees of glare. Except a small difference in the last calculation of DGP, the other results are identical.

5.1.5. Conclusions

This first chapter has been useful to extract the first conclusions of this study which analyses glare under sunlight conditions. The three experiments of this chapter have been realized using the same interior. It is an office space where the desks are correctly distributed in perpendicular to the façades (Tregenza & Wilson, 2011). This is a classical scenario tested in other researches which study the risk of glare. However, the windows are quite peculiar in that particular occasion. They are elongated and distributed along the two façades (facing south and north) and the saw-tooth roof (facing north) which provides overhead daylight (figure 5-1). Initially, the balance of daylight is better in that multi-side-lit interior than in a side-lit one. Then, the daylighting conditions are appropriate to discuss the limits between comfort and discomfort in terms of glare.

The second specificity of this interior concerns the view through the window. Mainly, the subjects perceive portions of sky because the interior is located in the top of a building, which is taller than its neighbours. Thus, it can be said that the view through the window and the reflected sun patches are equivalent in terms of degrees of information. Considering those conditions, the answers to the questionnaires of the first experiment demonstrate that the subjects' judgement of the degree of glare is equivalent when they judge the glare effects of the sun patches or the view through the window. In accordance, the measurements reveal that the luminances of the sun patches and the portions of sky have the same order of magnitude. Moreover, there is no signal of negative reaction when the users judge the presence of the sun patches answering the questionnaire. Conversely, they tend to identify their presence with positive meanings. Therefore, the questionnaires contribute to validate the use of the glare indexes when there are sun patches in the scenes. Consequently, the next experiments analyse the risk of glare in accordance to the results of the glare indexes, without using more questionnaires.

The first experiment tests three different visual fields. They assess the risk of glare at nearly the same hours, with comparable positions of the sun (at the back of the user). The second experiment uses the results of the first visual field, watching the PC screen. They are compared to the results of an equivalent visual field but considering a completely different position of the sun. Its new position is in front of the user, who faces its halo in the sky (through the window) and the reflections of its direct radiation on the surfaces (interior space). These new conditions are named “extreme sunlight conditions”. The calculations of the glare indexes demonstrate that the risk of glare is obviously higher. However, even if the luminances of the glare sources are clearly extreme (approx. 10.000 cd/m2), the DGI index describes the situation as disturbing (DGI=25) but still far away from intolerable (DGI>31). It can be appreciated that the sunlight conditions are also responsible of high values of the average luminance of the scene and the background, which reduce the risk of glare.

The third experiment of this chapter uses the same space and sunlight conditions (similar hour and day under clear skies). However, the observers' visual fields change. The experiment analyses two points of view corresponding to general sights which can also be responsible of the user’s decision of changing the lighting conditions (frequently when the user enters the space). Apparently, the scene could be considered as specially glaring because many sun patches are reflected on the surfaces, in particular on the ceilings. Nonetheless, the type of reflection and low intensity of the horizontal sun beams explain the low luminance levels of the sun patches. They increase the average luminance of the scene and reduce the pixels included in the glare source. The corresponding DGI indexes describe situations where the risk of glare is far away from being considered as disturbing. Again, the sun’s position is relevant. The DGI indexes are higher when the sun virtually faces the observer but they still remain clearly under the level describing a disturbing situation.

The previous comments judge the risk of glare mentioning repeatedly the results of the DGI index. Its formulation is based on a logarithmic formulation that compares the luminance of the sources and the background. Apparently, the results correspond with the users’ judgements. The current work, as previous researches (Hopkinson, 1970/71, 1972; Chauvel *et al.* 1982; Iwata *et al.* 1990/91; Boubekri & Boyer, 1992; Velds 2001; Wilks & Osterhaus, 2003), seems to validate this correspondence. However, the results of the DGP index seem questionable. None of the results describe a disturbing situation. Even more, if the worst situation is considered, i.e. when the subject would hypothetically work watching the PC screen while facing the sun’s position, the DGP result equals 0.32 and stays under the threshold that describes a perceptible glare

(DGP > 0.35). Under the same lighting conditions, DGI describes the situation as disturbing. The DGP formulation is based on the addition of two terms. The first term is equivalent to the expression contained in the DGI formulation that compares the luminance of the glare source and the background. The second term considers the vertical illuminance on the lens (Ev). Apparently, this illuminance must be very high to describe the scene as glaring. The results verify this statement that was mentioned by Wienold (2010) when he defined the DGP index for the first time.

Finally, the three experiments of this first chapter are useful to check the repercussions of changing the threshold that defines the pixels included in the glare source. The calculations are duplicated, using two definitions: Lav*7 and Lav*5. This exercise was previously done in the chapter corresponding to the methodology and the particular settings for the calculations. It was considered appropriate to continue with this verification in this first chapter of the experimental studies. The results show that the differences in the results of the luminance of the glare source and the background are not responsible of significant differences in the calculation of the glare indexes. Consequently, the calculations in the next chapters will only use one of the two thresholds. In addition, two different centre of bracketing were tested in the last experiment of the current chapter. Equally, there was no repercussion in the final results of the glare indexes. Then, this procedure will not be repeated in the next assessments.

5.2. Side-lit meeting rooms

5.2.1. Introduction

The previous chapter analyses the risk of glare in a multi-side-lit office. In terms of balance of daylighting, the conditions of that space are ideal. The orientation and design of the windows reduce the risk of perceiving directly the sun beams when the user is working whereas a framed view through the windows is permitted. The desks are distributed in perpendicular to the windows, as recommended by the guides of good daylighting practise. These conditions have been ideal to assess the risk of glare in the borderline between comfort and discomfort, when the answers to the experiments are not obvious. By means of questionnaires and glare calculations, the last chapter demonstrates that the risk of glare is low in these well-lit spaces, even if there are sun patches in the scene. The questionnaires indicate that there is not negative prejudice against the presence of the sun patches. Moreover, the measurements show that the luminances of the sun patches are equivalent to those of the portions of sky. There is only a specific moment during the day when the risk of glare is higher. It corresponds to the lowest positions of the sun when the user perceives its halo in the sky and the specular reflection of its beams on the interior surfaces. Even so, the maximum DGI index equals 25, just one unit above the borderline that describes a disturbing situation.

Hence, the current chapter pretends to assess other situations where the risk of glare under sunlight conditions is presumably higher. However, the experiments done in that second chapter do not pretend to assess exceptional spaces or sunlight conditions. In fact, the conditions are more common than those of the previous chapter. Firstly, the spaces are side-lit spaces, certainly the most common situation, even if it creates unbalanced situations of daylighting. Figures 5-21, 5-22 and 5-23 describe the four interiors where the experiments of this second chapter took place. All have a glazed façade from the window ledge until the ceiling, except the last space that has a totally glazed façade.

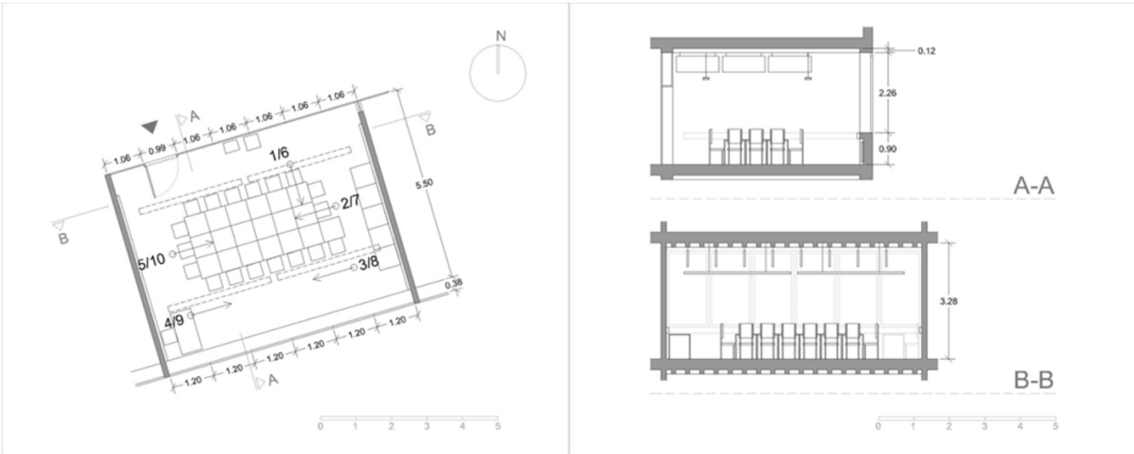


figure 5-20: London, SABE, University of Westminster, 2nd floor, room M208

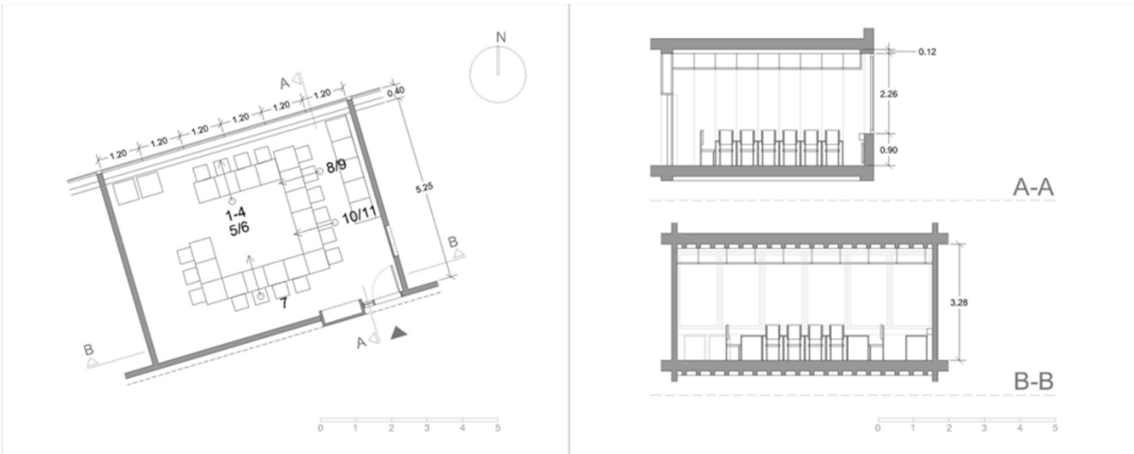


figure 5-21: London, SABE, University of Westminster, 3rd floor, room M327

The diversity of the visual fields in relation to the window's position is the second fact that permits to describe the daylighting conditions as common. These conditions are no longer as ideal as they were in the previous chapter. The current experiments consider directions of sight in parallel to the window but they also include the critical positions when the sight faces the exterior (in perpendicular to the window). That circumstance implies central positions of the glare sources and, in accordance, a higher risk of glare. That is why all the analysed spaces are meeting rooms. Their usage requires the meeting around a central table and connotes multiple horizontal sights. All these positions are possible in offices or classrooms, which are the most common spaces in the glare studies (Hopkinson, 1949; Ne’eman, 1976; Wienold, 2010), even though the objective of the vision, which is focused in the centre of the visual field, and its lighting conditions are not the same (the face of an interlocutor unlike a luminous screen or a blackboard).

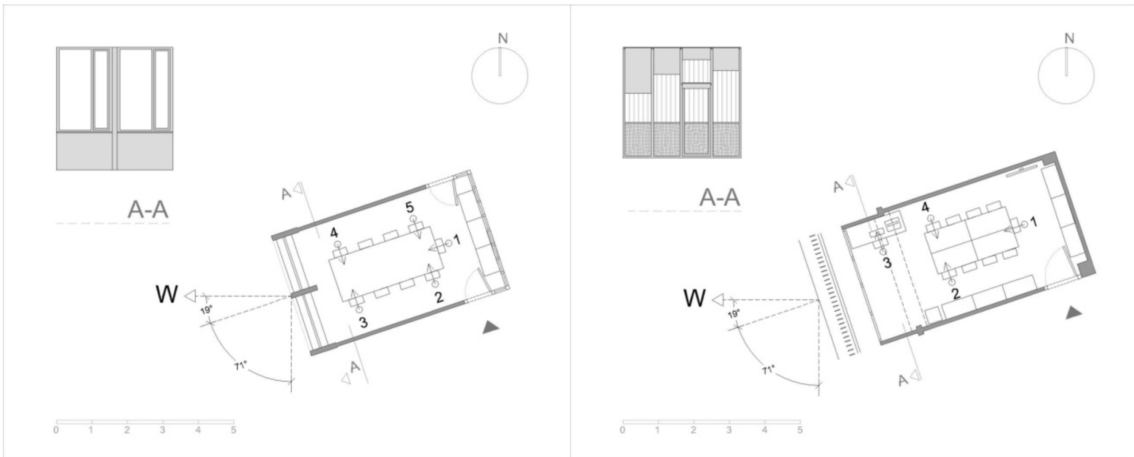


figure 5-22: Barcelona, ETSAB, UPC, 4th floor 8 (Urb.) - 7th floor, (CiS)

After fixing these two conditions (side-lit interior and meeting usage), the experiments pretend to consider other variables to enlarge the extension of the conclusions' relevance. The two first experiments are located in London (figure 5-20 and 5-21) while to latter two occur in Barcelona (5-22), with considerable differences in latitude and sky conditions. The two cases located in London compare two opposite orientations (south and north), while the more extreme cases of Barcelona face west, which can be considered in terms of daylighting as symmetrical to the east orientation. In relation to the lighting control systems, the London cases analyse the effects of the artificial lighting pretending the rebalance unbalanced lighting situations. In addition, two different sizes of glare sources are assessed thanks to the use of the shading devices. In Barcelona, due to the extreme conditions, the experiments analyse the contribution of different alternatives of standard shading devices in order to reduce glare. Finally, the experiments consider different days and hours. All they pretend to study the most unfavourable conditions, when the risk of glare is higher. In London different dates of summer are compared whereas in Barcelona, the experiments compare dates around the equinox. In London, the sunbeams are mainly vertical, whereas in Barcelona, they are clearly horizontal, affecting notably the calculated indexes of glare.

Considering all the previous, the assessments of this chapter will be useful to find the answers to the following questions:

- Is it the risk of discomfort glare less probable when the sun patches are inside the room or when they are outside the room?

- Consequently, is there more risk of discomfort glare due to sunlight in south-facing spaces than in north-facing spaces?

- Are the effects of artificial lighting sufficient to correct a situation of discomfort glare caused by sunlight?

- Is the risk of discomfort glare higher when the sun patches are due to horizontal sunbeams (west-facing spaces)?

- Consequently, are the west façades the worst in terms of discomfort glare?

- Considering these west façades, are the shading devices a solution? Or, do their surfaces create new patches of brightness which are liable to become unexpected sources of glare?

5.2.2. Sun patches inside a south-facing meeting room

First variable: 2 different hours – constancy of the glare index results

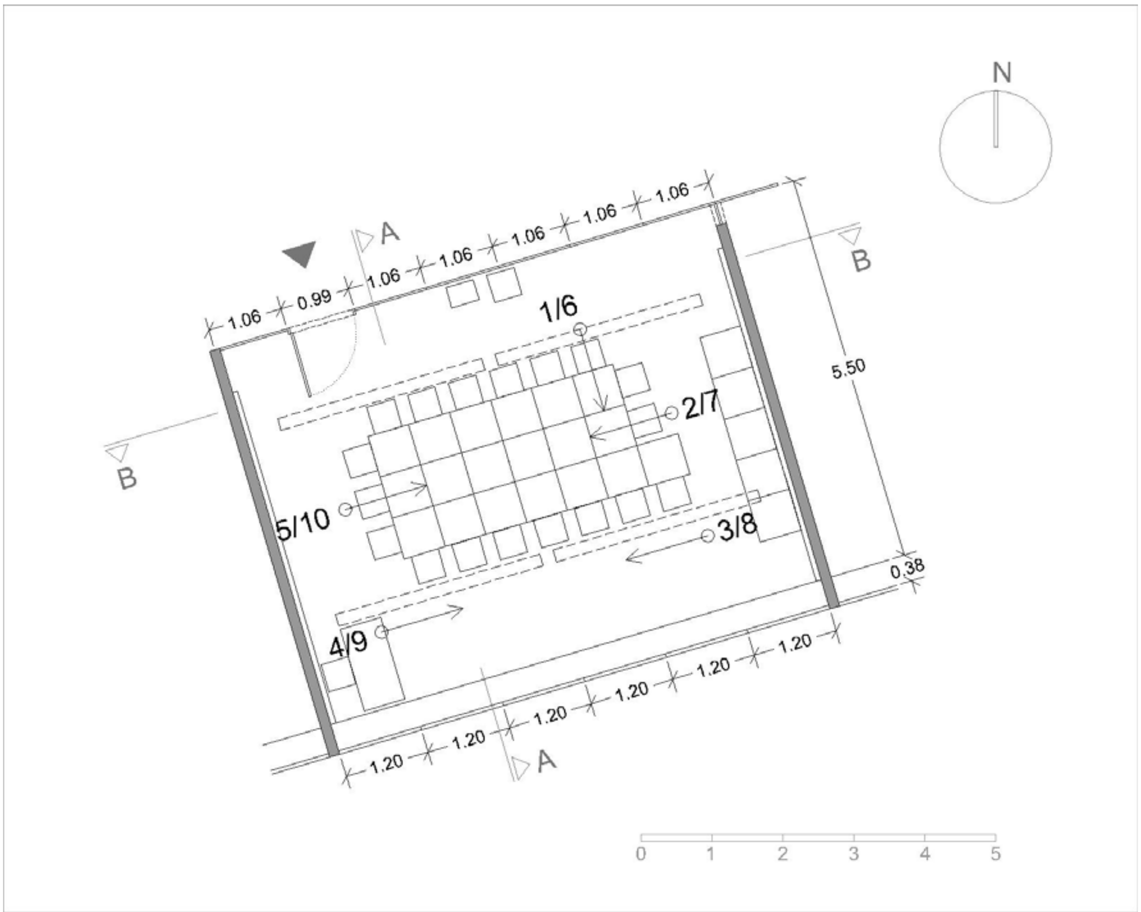
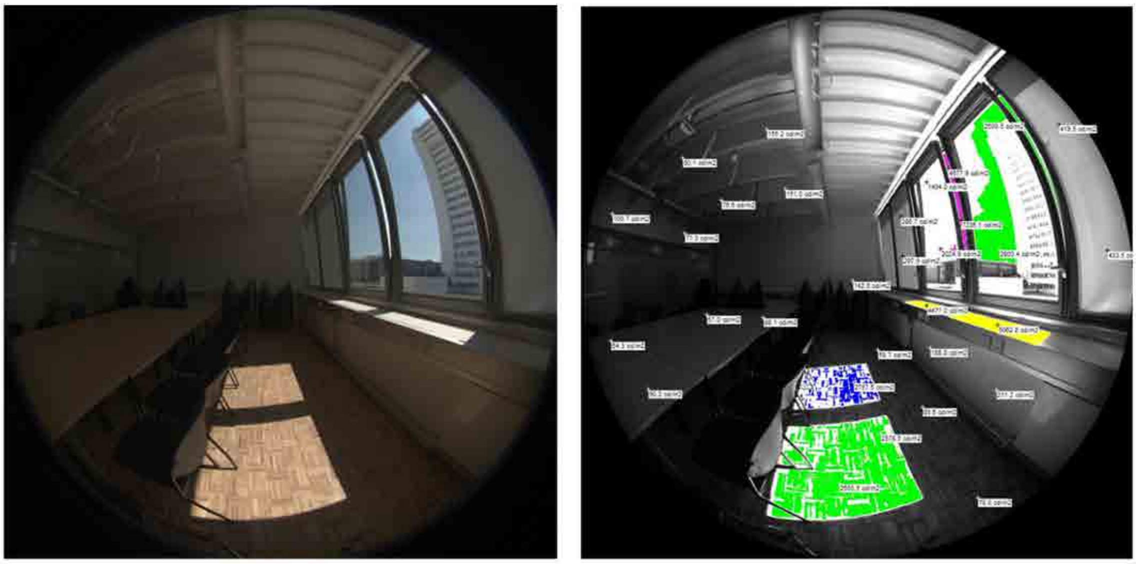


figure 5-23: Room M208 and five VF: comparison of the glare effects in a south facing space, depending on the user's position, size of the window and hour

The first experiment of this second chapter takes place in a meeting room facing south (figures 5-20 and 5-23). This room is used for interactive lessons where 18 students are seated around one big table, facing each other. Amos Rapoport (2005) defines this type of room as a 'classroom-seminar', unlike the traditional classroom where the students, being seated in parallel to the windows, pay attention to the teacher or the blackboard - which Rapoport names the 'classroom-lecture'.

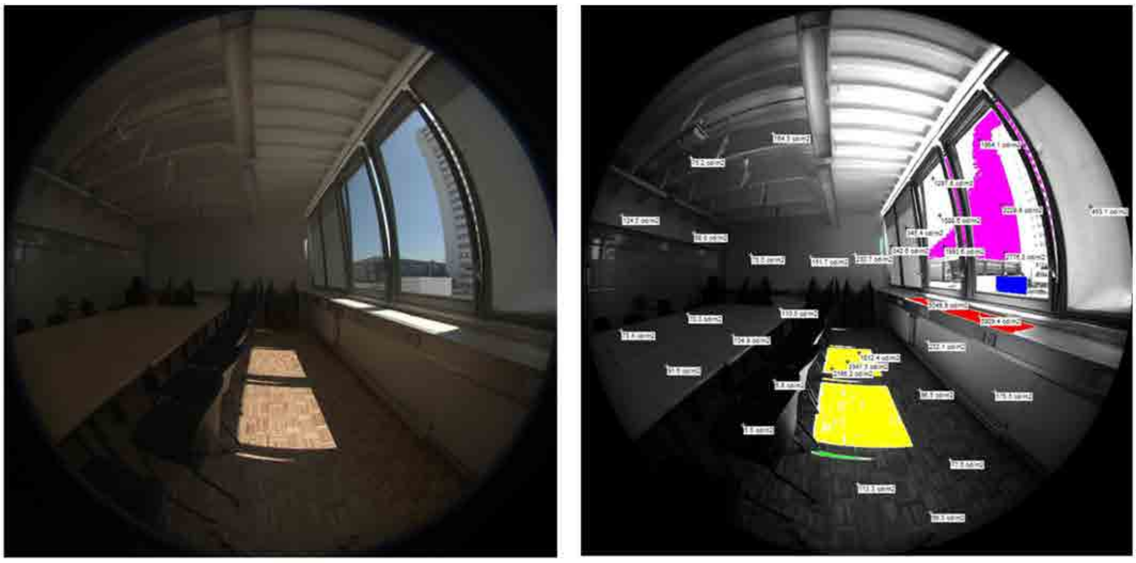
This experimental room was recently refurbished. By means of a lux meter and a luminance meter, the reflection coefficient of the finishes is deduced. The lateral walls and ceiling are painted in a light white (r=0.9 approx.). The floor is parquet and combines light and dark tones of wood (average r=0.4 approx.). The last relevant surface is the big table, which is also finished in wood (r=0.35 approx.). The wall that is on the opposite side to the window is in glass and permits partially the view of the aisle through it. Despite that, the back of the room stays darker than the perimeter next to the window, since the artificial lighting is turned off in the aisle. Therefore, it remains appropriate to consider that this space is laterally illuminated, thanks to a single façade.

The view through the window is quite tidy. A big proportion of sky is visible in combination with two volumes of modern architecture that belong to the same project as the School of Architecture. The design of the façade includes a manual shading device; each window incorporates an interior roller screen that limits considerably the transparency. The experiment considers this device as a substantial modification of the façade. It repeats the assessments with two different positions of the roller screens. Firstly, the most extreme roller screens are down and the view through window is framed in the centre of the façade. This configuration is called “L” and the corresponding visual fields are numbered from 1 to 5. Secondly, all the roller screens are up and the view through the window is freely permitted. This configuration is called “XL” and the corresponding visual fields are numbered from 6 to 10. The figures 5-24 and 5-25 show the space using the configuration “L”. These two figures show the same visual field. They compare the glare effects corresponding to two different hours of the day (12am and 1pm). This is the variable that this chapter pretends to highlight. Looking at the photographs, the slightly different position of the sun patches is perceptible. The figures 5-26 and 5-27 show the same comparison, related to the same visual field, but changing the configuration of the façade to the “XL” position. The directions of the shadows are useful to deduce how the sun’s position is changing. Thus, the mentioned figures (5-24 to 5-27) show the same visual field (number 4) under different sunlight conditions. In addition, four other visual fields are analysed by the experiment (figure 5-23).



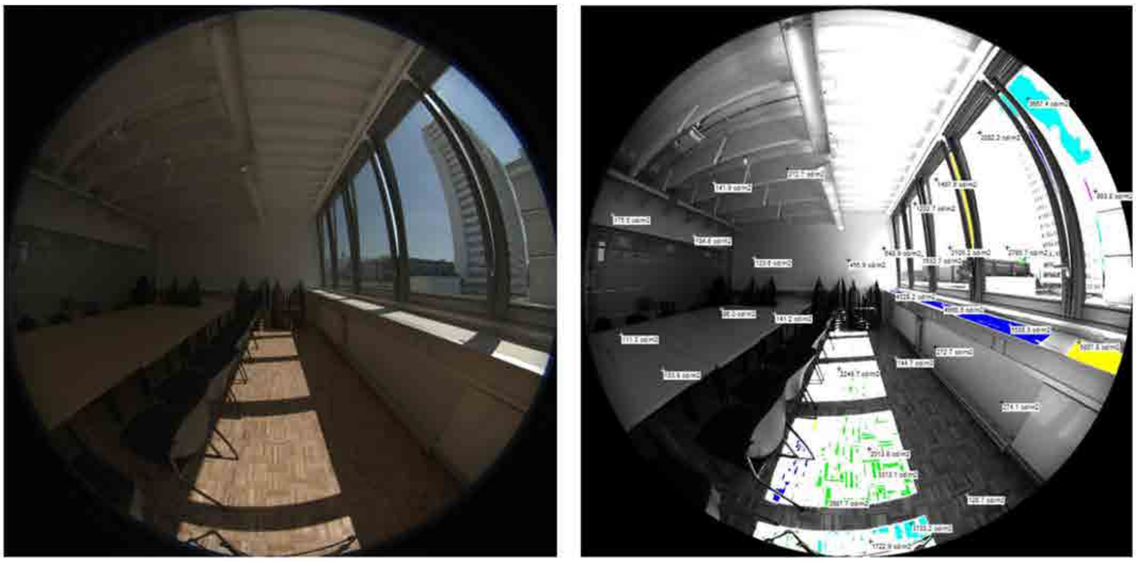
Shading: YES | Lighting: OFF 1 | VF 4 (4) 19/07/13 12:09-12:13 | DGI (F) 12 DGI (E) 18 DGP 0,26 Ev 1483 lx

figure 5-24: VF 4 (4): data and images of HDR and Evalglare (window size “L”, hour “12h”)



Shading: YES | Lighting: OFF 2 | VF 4 (4) 19/07/13 12:54-13:14 | DGI (F) 12 DGI (E) 19 DGP 0,26 Ev 1387 lx

figure 5-25: VF 4 (4): data and images of HDR and Evalglare (window size “L”, hour “13h”)



Shading: NO | Lighting: OFF 1 | VF 4 (9) 19/07/13 12:09-12:13 | DGI (F) 11 DGI (E) 14 DGP 0,28 Ev 1923 lx

figure 5-26: VF 4 (9): data and images of HDR and Evalglare (window size “XL”, hour “12h”)

Shading: NO | Lighting: OFF 2 | VF 4 (9) 19/07/13 12:54-13:14 | DGI (F) 10 DGI (E) 15 DGP 0,27 Ev 1708 lx

figure 5-27: VF 4 (9): data and images of HDR and Evalglare (window size “XL”, hour “13h”)

In total, the experiment compares the glare effects of five visual fields. Four visual fields consider positions in parallel to the windows. The visual field named 5 is similar to number 4. It simply describes a deeper position in the room. The visual fields 2 and 3 correspond to the symmetrical positions to numbers 4 and 5. Thus, they face the sun's presence or at least its halo. Finally, the visual field named 1 is totally different. It describes a position in perpendicular to the window that faces directly the glare sources (window and sun patches).

The figure 5-28 compares the results of the five visual fields using graphs with vertical bars. A grey scale permits to differentiate the two different hours that are analysed (12h and 13h). On the left side, the graphs present the results that correspond to the configuration named "L", whereas the right side shows the results related to the "XL" configuration. In vertical, the graphs show the calculations of four relevant results. On the top, the graphs present the calculations of the luminance of the background (Lb) which helps to understand the next results, the DGI indexes. After that, the graphs indicate the vertical illuminance on the lens (Ev) which partially explains the next results, the DGP indexes.

If we consider the configuration named "L", the DGI index is similar for the visual fields 1, 3 and 4. The result varies between 18 and 20. The contrast is perceptible (above 18) but is far from being disturbing (above 24). However, the same degree of glare does not describe similar scenes. The first visual field is notably different. The sun patches, which are only visible on the windowsill, are small. The biggest sun patches, which are reflected on the floor, near the window, are not visible from this position because the table obstructs their vision. Besides, the view through the window is quite limited in the "L" configuration. It combines the modern façades of the neighbours (facing north) and a vertical portion of clear sky. The sky and the white parts of the façade are included in the glare sources. Even if they are small, these glare sources are susceptible to cause glare because they appear in the centre of the vision and they are confronted to a quite dark background (Lb=177-187 cd/m2) in comparison to the background of the visual fields named 3 (Lb=290-296 cd/m2) and 4 (Lb=336-409 cd/m2). These two visual fields present a clearly different situation. The sun patches are visible on the windowsill and mainly on the floor. They have a leading role in the daylighting conditions of the scene.

Unexpectedly, their glaring effects are not disturbing because its presence provokes a noticeable increase of Lb, which balances the lighting conditions.

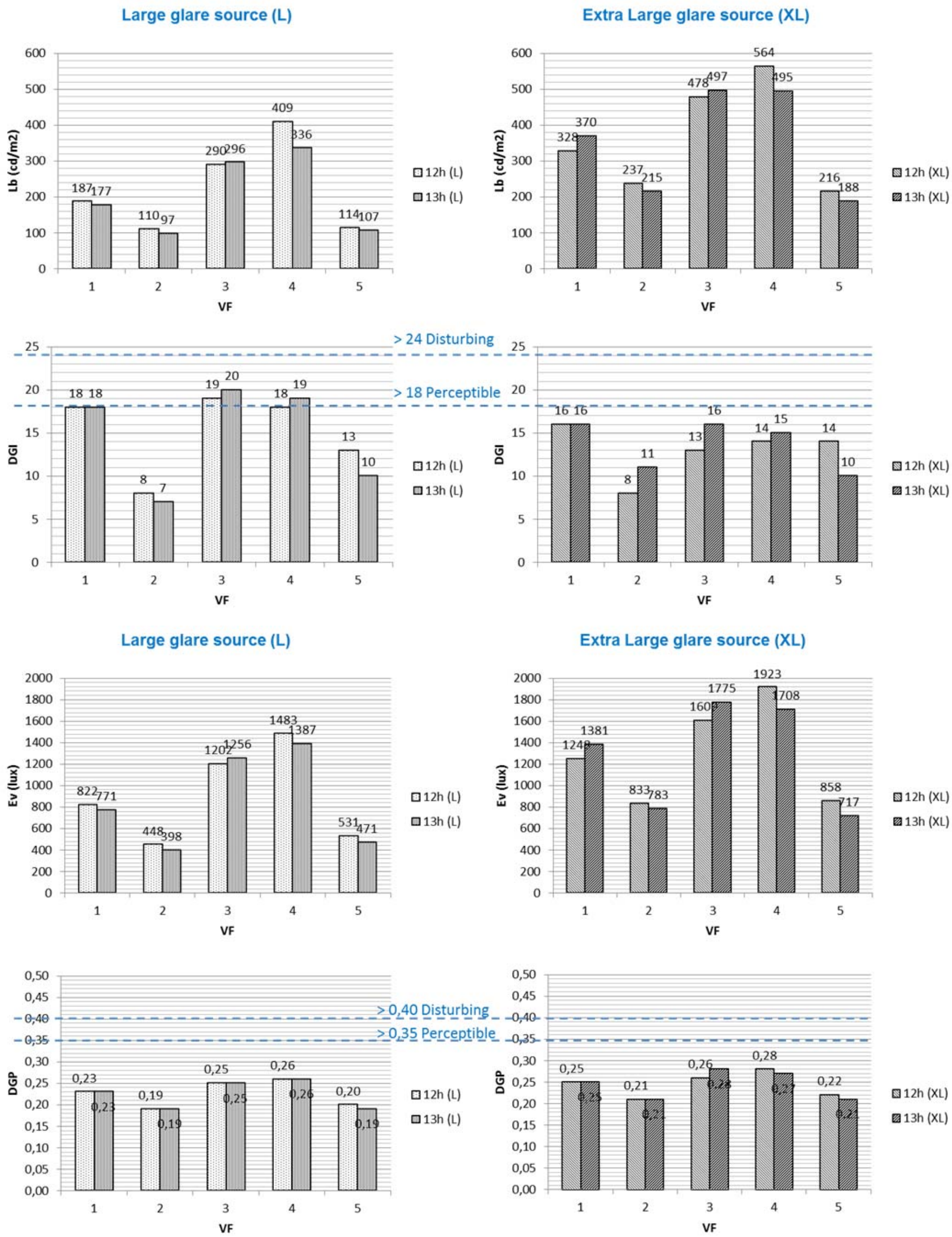


figure 5-28: Results room M208: Lb, DGI, Ev and DGP of the five VF, with two window sizes (L, XL), at two different hours (12h, 13h)

The comparison of the latter two visual fields shows that the glare index of the visual field numbered 3 (DGI=19-20) is a bit higher than the corresponding to the number 4 (DGI=18-19). The reason is that the first faces the sun's position (although it is hidden by the scene) and confronts a darkest background.

The glare indexes are far lower for the visual fields number 2 (DGI=7-8) and 5 (DGI=10-13). In these the cases, the interior view predominates within the visual field. Then, the glare sources are small and peripheral. As in the visual field named 1, the main source of glare is the view through the window, since the sun patches are only visible on the windowsill. Again, the sun patches that are reflected on the floor are hidden by the table. In these situations, we might even say that the sun patches reduce the risk of glare because they increase the background's luminance and reduce the contrast between the interior and the exterior. Although the background's luminance of these two visual fields is similar, the glare indexes differ notably. This is because of the view through the window, which is not equivalent in that urban context. In the visual field named 5 the portions of sky are bigger than in the named 2.

The results of the DGP index, which are related to the configuration named "L", express similar relations between the five visual fields. Again, the results assess a similar perception of glare for the cases 1, 3 and 4. However, there is a different correspondence if we link the calculated values to the presumable perception. The results of these three visual fields vary between 0.23 and 0.25. These results are clearly far from the values describing a perceptible contrast (DGP=0.35) or a disturbing glare effect (DGP=0.40). It has been mentioned before that the illuminance on the lens (Ev) affects notably the final result of the DGP index. Apparently, even with the high brightness of the scenes named 3 and 4 (Ev=1200-1500 lx approx.), it is insufficient to consider those scenes as glaring. Once more, the calculations of the DGP index seem to emphasize that this index requires more adjustments to obtain reliable results in terms of perception. Equally, it seems that these adjustments should improve the sensitivity to the variations of light. In this experiment, all the results are equal even if the lighting conditions change between 12 am and 1 pm.

This chapter starts underlining the idea of a certain stability of the sunlight conditions. The experiment compares the glare effects considering two different hours (12h and

13h approx.). The analysis of the configuration named “L” shows very small differences in the DGI results. The first four visual fields show only one unit of difference. Only the fifth visual field presents a considerable difference of three units. The cause of this specific difference is difficult to argue, since the values of Lb and Ev are quite similar for the two hours. Equally, the appraisal of the images of Evalglare does not describe significant difference regarding the pixels included in the glare sources. Despite this exception, it seems appropriate to affirm that there is constancy in the results. The reading of the DGP results supports the same argument, although the lack of sensitivity to small variations in the conditions of lighting, which has been mentioned before, diminishes the reliability of this affirmation by means of this index.

Once reviewed the results of the configuration named “L”, it is interesting to see if the behaviour is similar when the configuration named “XL" is evaluated. The analysis demonstrates the same pattern in the existing relation between the DGI results of the different visual fields. Nevertheless, all the results are clearly lower. The highest result corresponds to the visual fields named 1 and 3. Its value equals 16, clearly below the threshold that describes a perceptible glare. Although a highest proportion of transparency in the façade could suggest a highest risk of glare, the opposite happens. The sun patches are more numerous but they remain near to the windows and far from the centre of the vision. They do not imply a significant increase in the risk of glare. Instead, their presence appears as favourable because they contribute notably to increase the average luminance of the interior. Consequently, there is an improvement in the balance of the daylight between the interior and the exterior.

The analysis of the configuration "XL" shows a lower stability of the glare effects when the time is considered as a variable. The results vary between one and four units, after one hour. The fast horizontal movements of the sun are the cause. They are responsible of two possible situations that provoke significant changes in the DGI results. Firstly, with an extensively glazed façade, more sky is visible and its luminance can change notably if the sun is in the back or the front of the supposed observer. Secondly, the windows arrive to the corners with the lateral walls of the room. When there is lateral solar access, the sun patches appear reflected on the lateral walls. These sun patches increase the risk of glare because they are closer to the centre of the vision.

The software Heliodon has been used to analyse the sun's position corresponding to the day of the experiment in London. The case of Barcelona has been added to compare if the same deductions are extensible in lower latitudes. Figure 5-29 shows the stereographic solar charts of these two locations. The software permits to specify the elevation and azimuth considering the solar hours. The table 5-1 is useful to prove that the variations are significant for the azimuth and less remarkable for the elevation. In terms of elevation, the differences between London and Barcelona are the highest around noon and almost disappear in the extreme hours. Regarding the azimuth, there is always a difference of 10 degrees more in Barcelona.

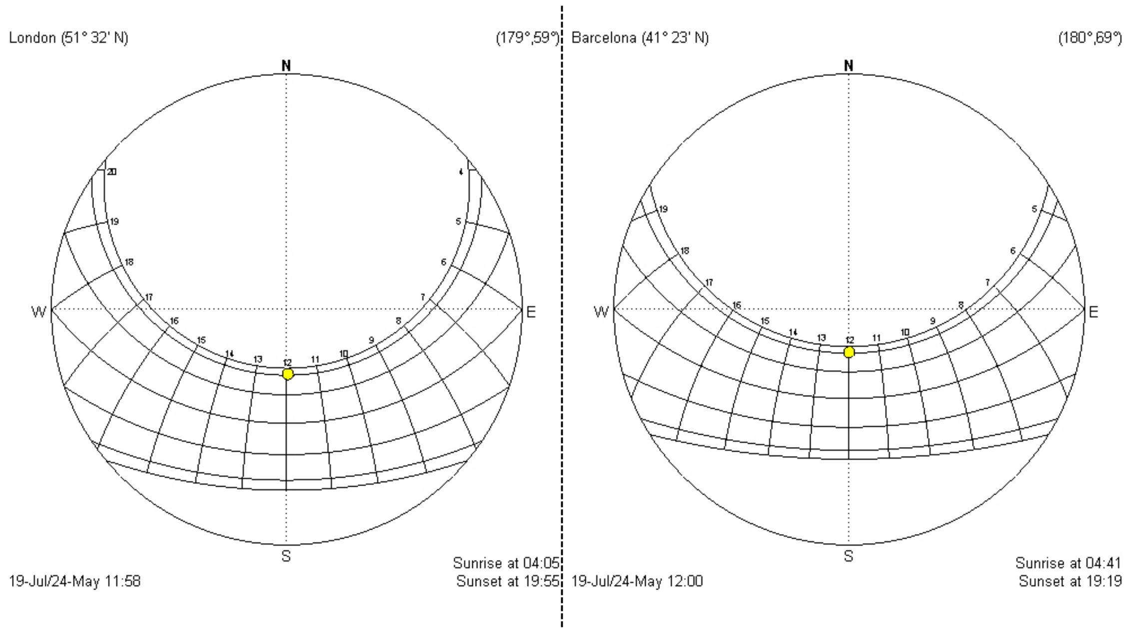


figure 5-29: Comparison of the stereographic solar charts of London and Barcelona, including of the specific day of the experiment (19-Jul / 24-May)

	ELEVATION		AZIMUTH*	
HOUR	LONDON	BCN	LONDON	BCN
12 h	59	69	0	0
11 or 13 h	57	66	26	36
10 or 14 h	51	57	49	60
09 or 15 h	44	47	66	76

*As a positive/negative deviation from South

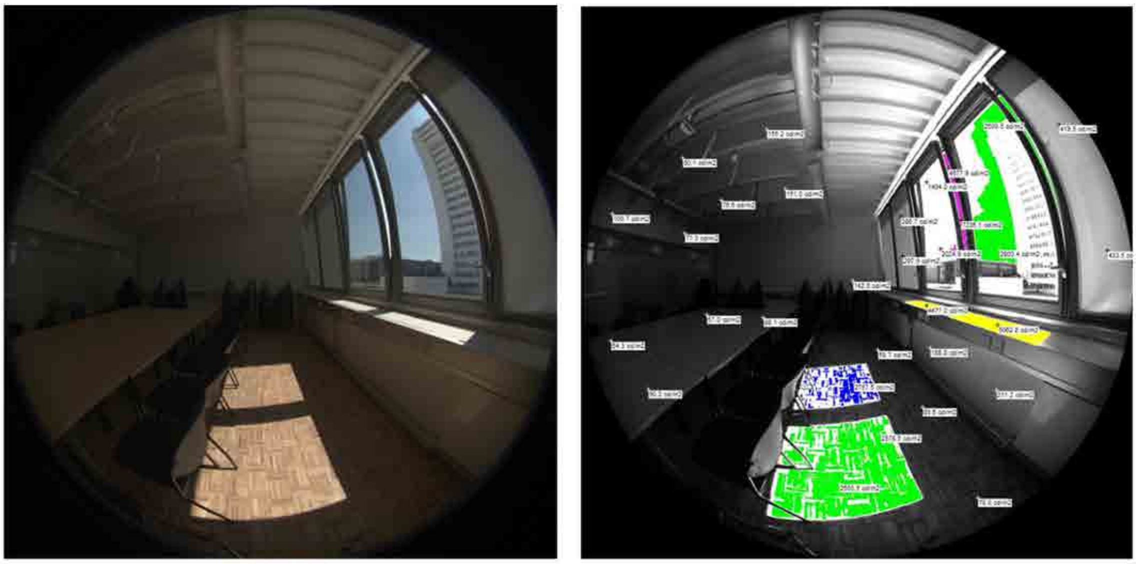
table 5-1: Comparison of the elevation and azimuth of the sun in the specific day of the experiment (19-Jul / 24-May)

Second variable: artificial lighting off and on – in order to minimize glare

The experiment of the previous chapter has unexpectedly demonstrated that a higher proportion of glazing in the façade was responsible of a reduction of the DGI index for all the analysed visual fields. The current chapter pretends to consider a second variable that could presumably have a similar effect of reduction of the glare indexes. We could expect that, in general, the presence of artificial lighting will increase the brightness of the interior surfaces. Consequently the artificial lighting would compensate the lighting differences between the interior and exterior and minimize glare.

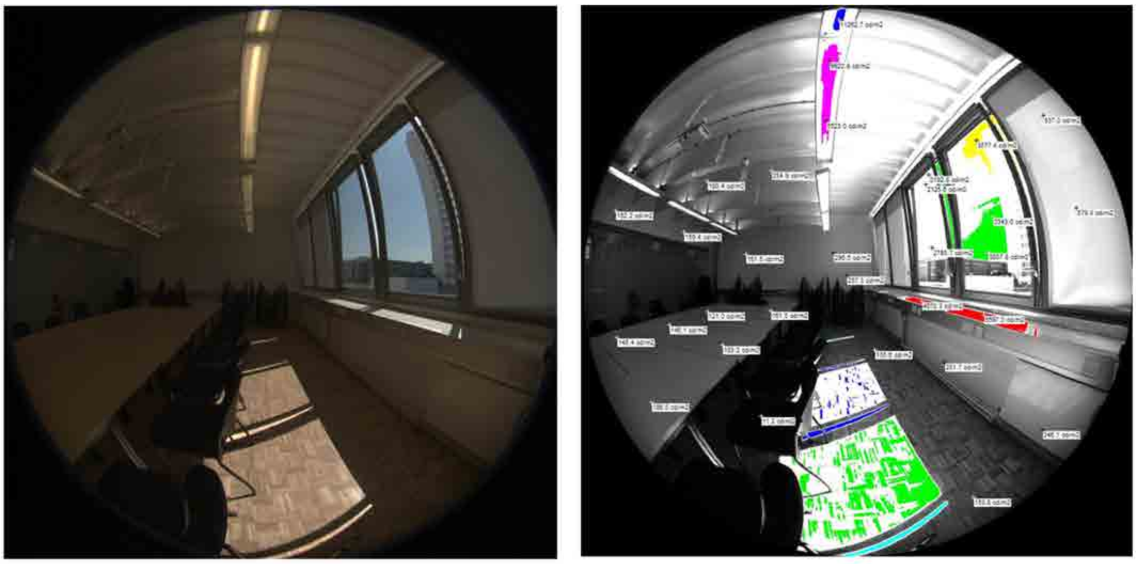
The same five visual fields of the previous chapter are assessed (figure 5-23). In fact, the results corresponding to the first hour (12h) are used again. They are compared to new assessments that add the artificial lighting. The lapse between the two measurements is less than one hour. Attending to the results of the previous chapter, presumably, the differences in terms of glare indexes between the two daylighting situations are almost insignificant. Thus, it is possible to compare the effects of the artificial lighting despite this lapse of time. The current experiment maintains the comparison of the two configuration of the façade, i.e. “L” and “XL”.

The figures 5-30 and 5-31 compare the scenarios of lighting corresponding to the visual field named 4, with the “L” configuration. Both images, i.e. the HDR image composition and the Evalglare representation of the glare sources, are useful to understand what happens when the artificial lighting is turned on. Apparently, the artificial lighting power increases the interior luminances, although the effects are low compared to the power of the sunlight presence. Even if these effects can rebalance a bit the lighting conditions, a second consequence should be considered. If horizontal views are considered, there is an almost inevitable risk of adding other new glare sources due to the lamps, even if the design includes strategies to minimize these effects (figure 5-31). Although the reading of the images introduces the clues to understand the risk of glare, the results of the glare calculations will be definitive to extract precise conclusions considering the two other variables, i.e. the five visual fields and the two configurations of the façade.



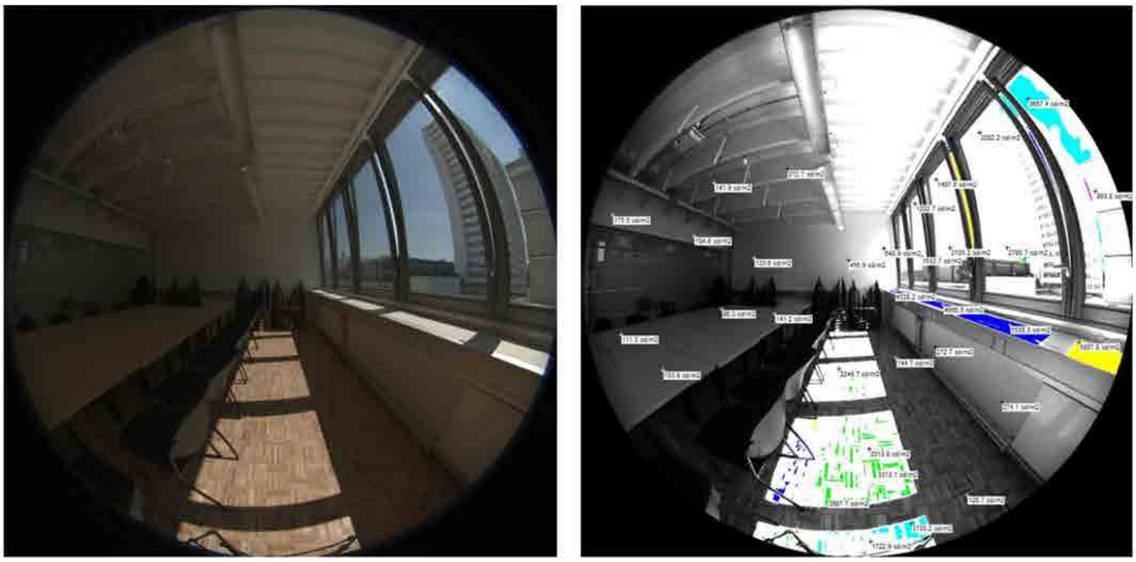
Shading: YES | Lighting: OFF 1 | VF 4 (4) 19/07/13 12:09-12:13 | DGI (F) 12 DGI (E) 18 DGP 0,26 Ev 1483 lx

figure 5-30: VF 4 (4): data and images of HDR and Evalglare (window size “L”, lighting “OFF”)



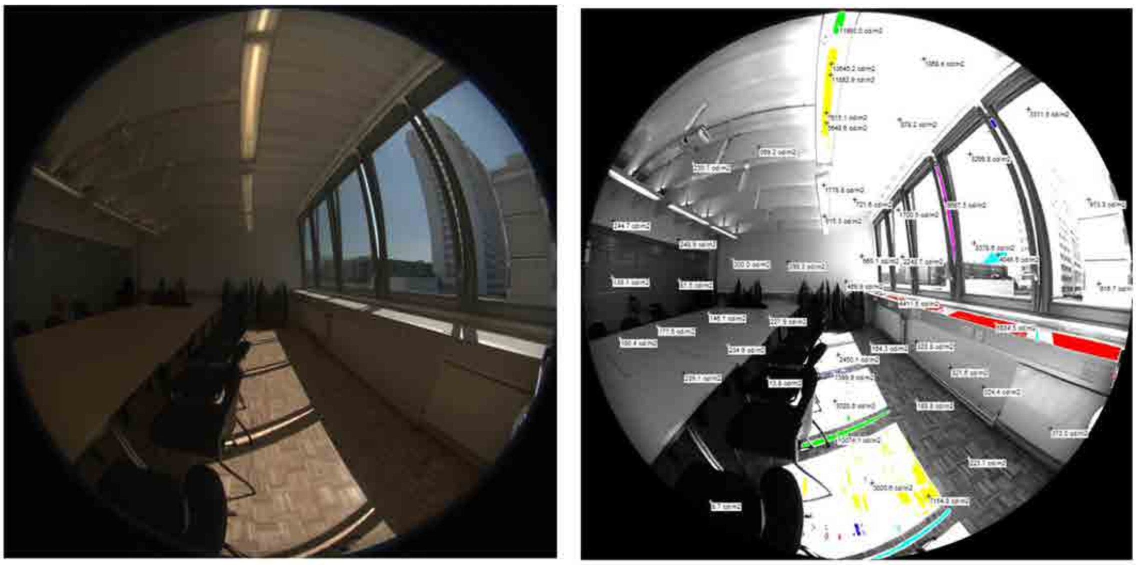
Shading: YES | Lighting: ON | VF 4 (4) 19/07/13 11:06-11:32 | DGI (F) 11 DGI (E) 17 DGP 0,29 Ev 2038 lx

figure 5-31: VF 4 (4): data and images of HDR and Evalglare (window size “L”, lighting “ON”)



Shading: NO	Lighting: OFF 1	VF 4 (9) 19/07/13 12:09-12:13	DGI (F) 11 DGI (E) 14 DGP 0,28 Ev 1923 lx

figure 5-32: VF 4 (9): data and images of HDR and Evalglare (window size “XL”, lighting “OFF”)



Shading: NO	Lighting: ON	VF 4 (9) 19/07/13 11:06-11:32	DGI (F) 10 DGI (E) 16 DGP 0,31 Ev 2478 lx

figure 5-33: VF 4 (9): data and images of HDR and Evalglare (window size “XL”, lighting “ON”)

Figure 5-34 repeats the same scheme of presentation of the results that was used in the previous chapter. In horizontal and vertical, the figure presents all the graphics that are necessary to expose the glare results (DGI and DGP) and the factors (Lb and Ev) which motivate those results. The graphs distinguish clearly the variables, i.e. the façade configuration (graphs on the left or right) and the presence of artificial lighting (with a grey scale in the vertical bars).

In the previous chapter, the analysis of the results starts with the interpretation of the glare indexes. Consecutively, the reading of the lighting parameters (Ev and Lb) permits to understand the reasons of those results. The current chapter proposes the inverse procedure. The chapter pretends to analyse if the intensity of the artificial lighting is sufficient to increase the interior lighting conditions and improve the light balance between the interior and exterior. Consequently, it is appropriate to start analysing how the lighting conditions change (Ev and Lb) and then evaluate its repercussions in terms of glare.

The experimental procedure implies a delay between the two lighting conditions (with or without artificial lighting). Even if the assessments were done with clear skies, it is very difficult to guarantee a perfect constancy in the daylighting conditions. An accurate reading of the results is necessary to identify whether they are just affected by the addition of artificial lighting or if the alternations in the sky are partially the reason. In order to analyse the constancy of the sky conditions and, as a consequence, focus the analysis in the repercussions of the artificial lighting, the results of the illuminance on the lens (Ev) offer the best clues. It is convenient to remember that the luminance of the background is not so reliable because this parameter includes a variable that discriminates the number of pixels included in its calculation, depending on a threshold (chapter 4.3).

Therefore, the figure 5-34 shows that if we consider the illuminance on the lens (Ev), the two configurations of the façade (“L” and “XL”) and all the visual fields, when the artificial lighting is turned on, the results show regular increases (between approximately 400 and 600 lux). Only three situations are an exception. They correspond to the visual fields 1, 2 and 3 of the “L” configuration. In these cases, the variations are lower (between approximately 200 and 270 lux). Presumably, a decrease in the sky's luminance affected these three results. Even if the luminance of the background (Lb) is not the best parameter to discuss the constancy of the daylight conditions, it is convenient to remark certain regularity when the artificial lighting is turned on. Its effects imply certain uniformity in the increase of these values (approximately between 70 and 120 cd/m2). This fact is also useful for the interpretation of the results of the glare indexes.

Once determined that the daylighting is constant enough, it is possible to analyse the glare indexes and the impact of the artificial lighting on them (figure 5-34). When the façade adopts the "L" configuration, the interior seems dark in relation to the exterior. In fact, attending to the results, the risk of glare starts to be detected in three visual fields (1, 3 and 4). Under these lighting conditions, the artificial lighting contributes with the reduction of the degree of glare although its impact is almost imperceptible. Three visual fields show a reduction of only one degree (minimum value describing the perception of changes in the balance of lighting). Only one visual field (VF3) presents a reduction of two units. Conversely, the last visual field of the five (VF2) is an exception. Its glare index increases one degree. This visual field is centred between the two lines of fluorescents (figure 5-23) and relatively far from the window. Even if the artificial lighting compensates the lighting conditions between the interior and the interior, from this position the two lines of lighting are clearly visible and they become sources of glare. Comparatively, the glare effects due to the vision of the sources of light are more injurious than the positive effects of the rise of the background's luminance.

The results corresponding to the "XL" configuration of the façade (figure 5-34) describe a similar situation. When the façade is almost completely glazed, the daylighting is clearly the main source of lighting and the contribution of the artificial lighting does not change substantially the luminance of the background. Conversely, the diffusers of the lamps appear in the visual fields and increase the number of glaring pixels. That is why two visual fields (3 and 5) do not register changes in their DGI results and the three other visual fields increase the degree of glare in two or three units.

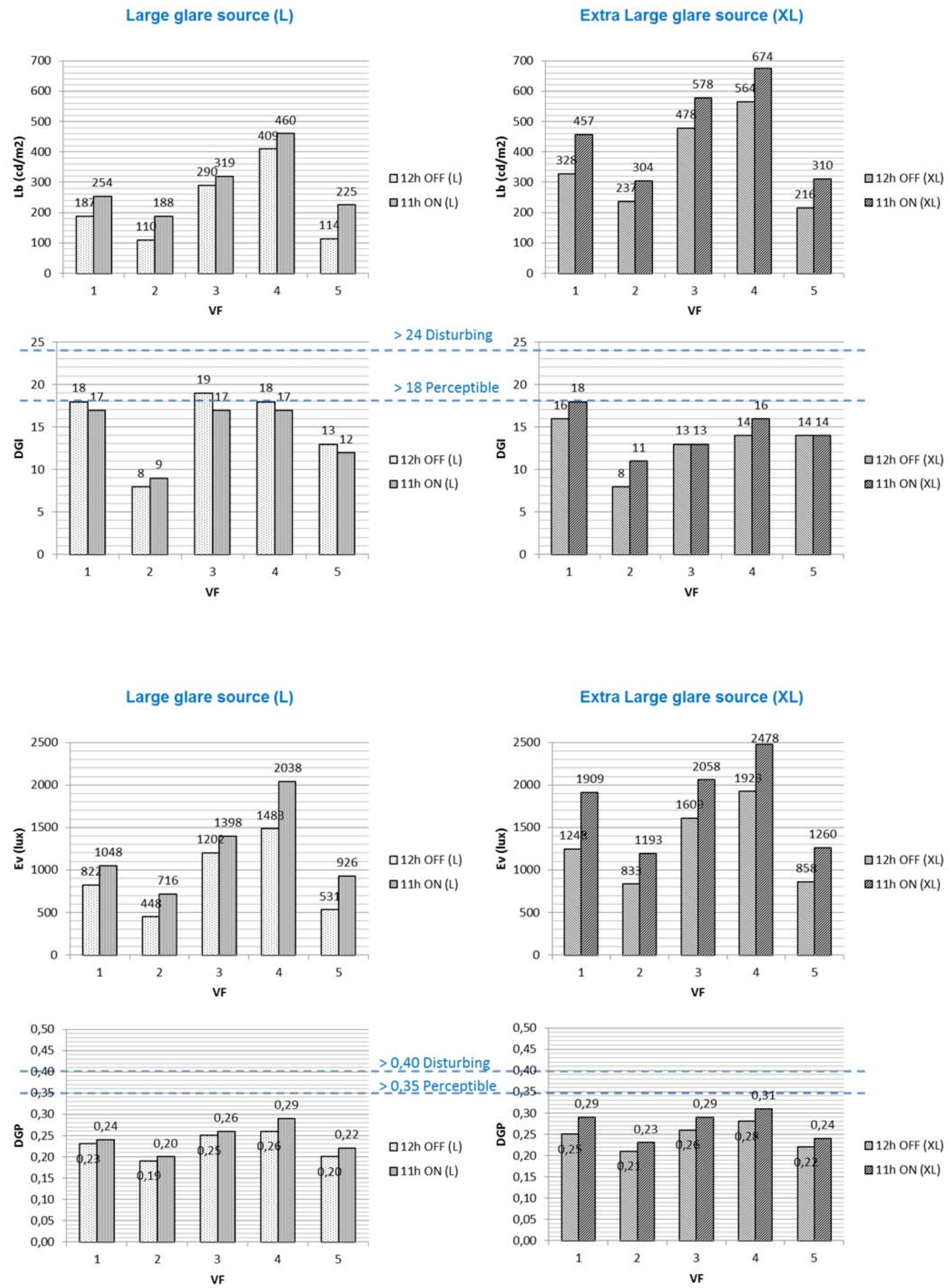


figure 5-34: Results room M208: Lb, DGI, Ev and DGP of the five VF, with two window sizes (L, XL) and two artificial lighting settings (OFF, ON)

If the results of the DGP index (figure 5-34) are considered, this case study criticizes again their reliability. Even if an improvement of the lighting balance seems obvious when the “L” configuration is analysed, the results contradict this experience. As it has been mentioned in previous situations, the impact of the Ev factor in the DGP formulation is notable. Apparently, the results of the DGP index are excessively dependent on the Ev value. In this experiment, the DGP calculations do not describe the nuances of the lighting conditions. When the artificial lighting is turned on, all the results increase the degree of glare because the value of Ev is higher. Equally, the results do not present sensitivity in relation to the glazed proportion of the façade. The results of the "XL" configuration do not present significant differences if they are compared to those of the "L" configuration.

In conclusion, this experiment demonstrates that, in a south facing room, when the sunlight illuminates the space and is responsible of sun patches close to the window, the power of the artificial lighting is insufficient to compensate the risk of imbalance of the lighting conditions (or glare) when the interior and exterior are simultaneously present in the visual field. Although insufficient, this effect of compensation can be slightly appreciated when the window represents a small proportion of the façade. However, it never happens when the glazing predominates in the façade. The next case study will be useful to assess if the repercussions of the artificial lighting are equivalent in a north facing room.

5.2.3. Sun patches outside a north-facing meeting room

First variable: 2 different dates – constancy of the glare index results

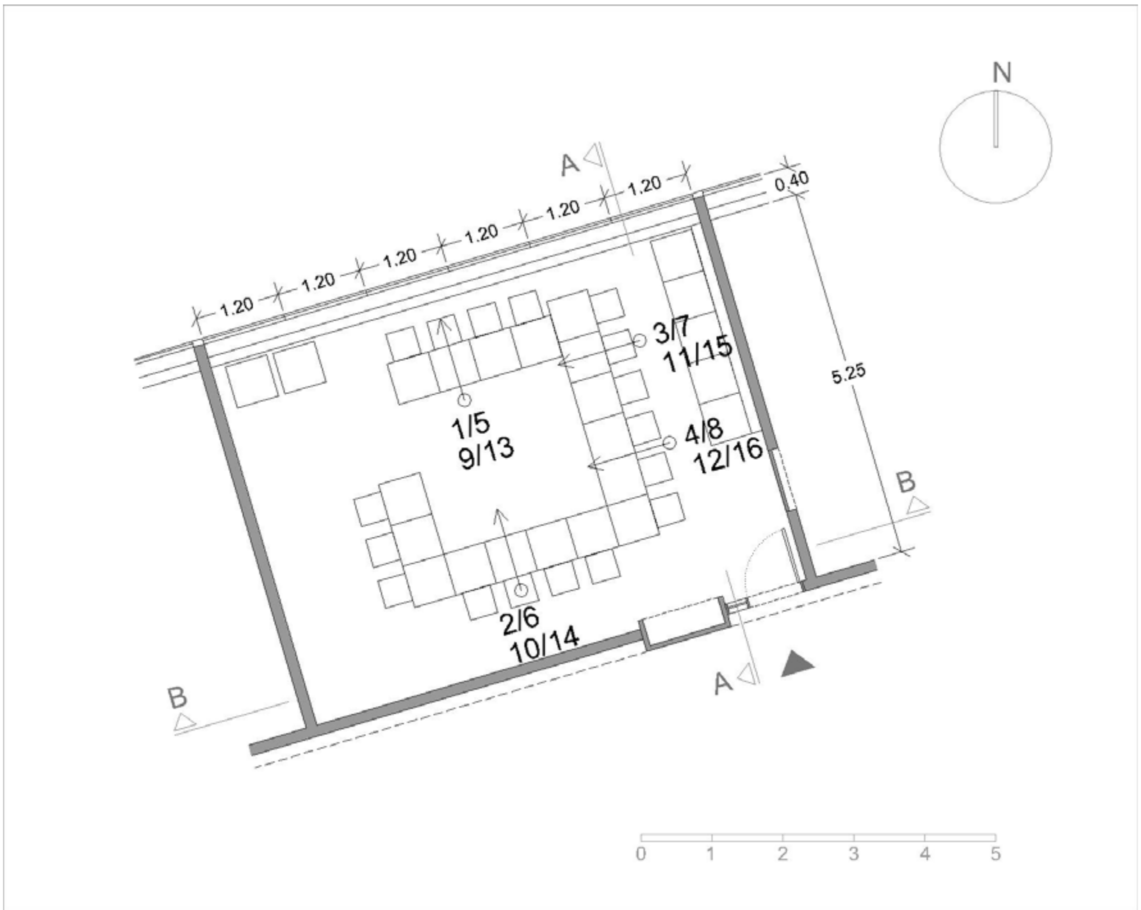


figure 5-35: Room M327 and four VF: comparison of the glare effects in a north facing space, depending on the user's position, size of the window and date

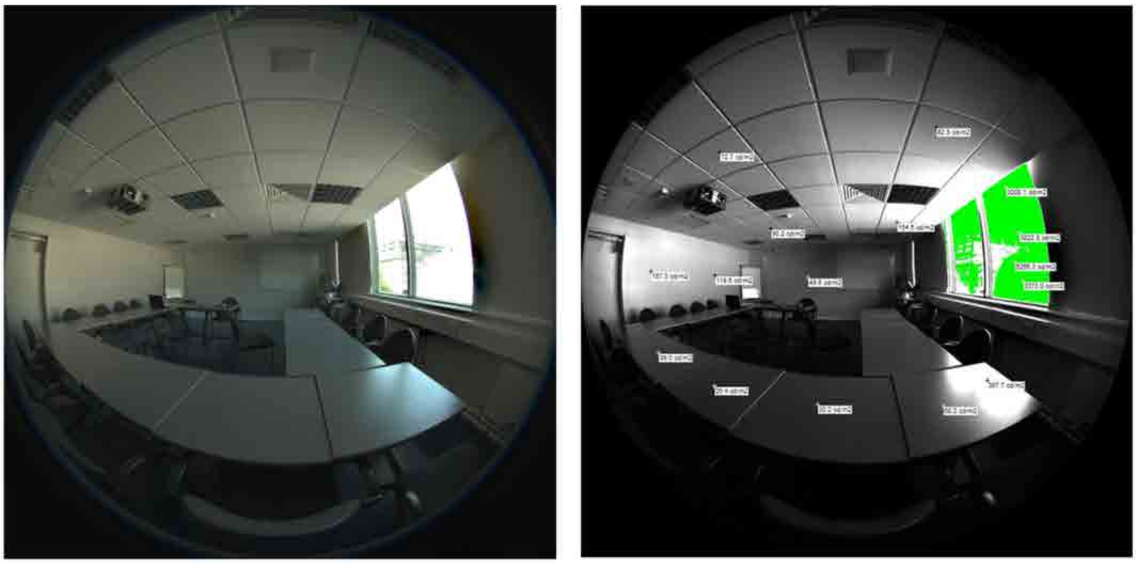
The third experiment of this second chapter takes place in a meeting room facing north (figure 5-21 and 5-35). In reaction to the previous case study, this experiment is useful to compare similar rooms under different lighting conditions (daylight and artificial light). The current room also corresponds to the previously type defined as 'classroom-seminar' that implies horizontal visual fields. The total capacity is identical (18 students approx.). They also sit around a central point, composing a partial square with the addition of single small tables.

Unlike the previous room, this room was not recently refurbished and preserves the original design. The false ceiling, composed of standard square pieces, includes the conventional luminaires with diffusers (figure 5-36). The ceiling is painted white (r=0.8 approx.), the walls are grey (r=0.55 approx.) and the floor is very dark, almost black (r=0.05 approx.). Finally, the tables are finished in grey (r=0.15 approx.). In general, this room is darker than the previous one, where the reflection coefficients are higher: ceiling and walls in light white (r=0.9 approx.), floor in wood (r=0.4 approx.), and table finished in wood (r=0.35 approx.). In addition, there is a second difference between the two rooms. In the previous room, the wall that is on the opposite side to the window is glazed (figure 5-33). In the current room, the equivalent wall is opaque and painted white (figure 5-36). The visual comparison of the two figures clarifies that the glazed wall is darker because its transparency permits the vision of a dark aisle where the artificial lighting was turned off. Instead, the white wall reflects the light coming from the window. Its frontal position facing the window provokes high luminances, which are even higher than those of the lateral walls.

The view through the window is quite tidy again. A big proportion of sky is visible in combination with the light-coloured façade of Madam Tussauds' Museum. In addition, this façade is facing south. The colour and the orientation of this façade, combined to the vision of the sky, are responsible of a bright view through the window. As in the previous room, the design includes manual shading devices. Although the glazing is identic, the fabric of the roller screen is different. They are totally opaque unlike the previous screens, which are partially transparent. Then, it is totally reasonable to suggest the same procedure for the current experiment. Changing the position of the screens and duplicating the assessments, it is possible to compare two ‘different’ façades according to two possible positions of the screens. Again, according to these two different positions, it is possible to compare the glare effects of two ‘different’ façades. Firstly, the “L” configuration corresponds to the situation when roller screens are down and the view through window is framed in the centre of the façade (figures 5-36 and 5-37). Secondly, the “XL” configuration lifts all the roller screens and the view through the window is freely permitted (figures 5-38 and 5-39).

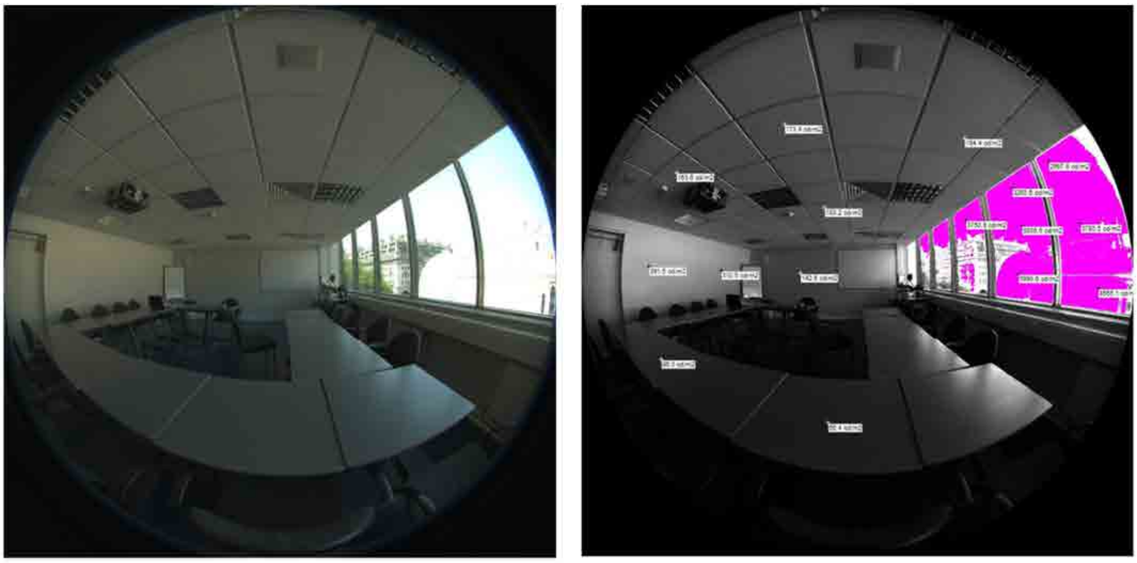
Shading: YES | Lighting: OFF | VF 3 (8b) 17/07/13 11:50-12:30 | DGI (F) 22 DGI (E) 18 DGP 0,24 Ev 710 lx

figure 5-36: VF 3 (8b): data and images of HDR and Evalglare (window size “L”, date “17/07”)



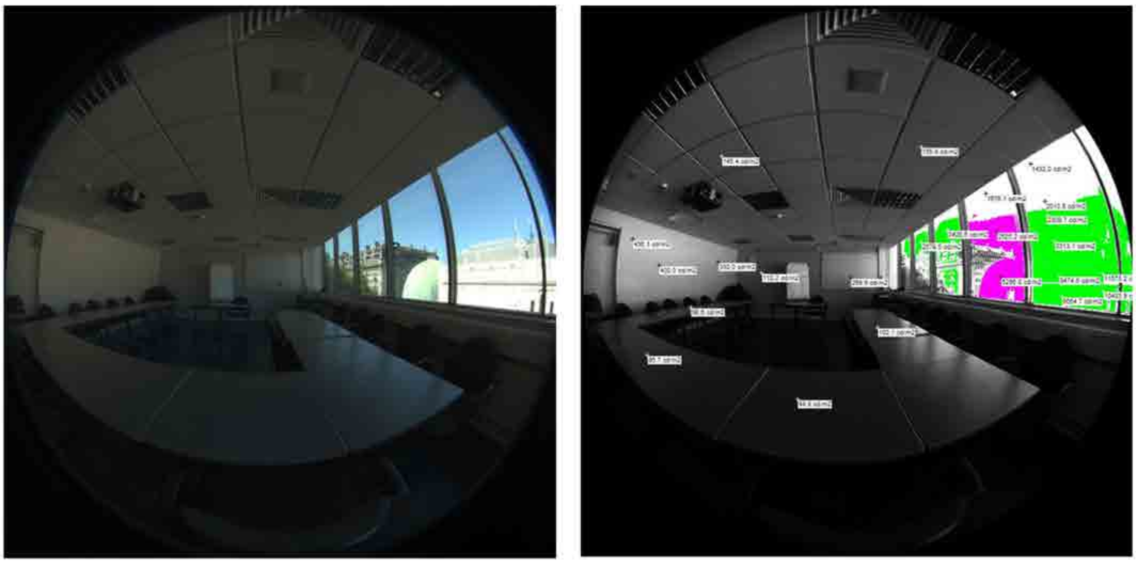
Shading: YES | Lighting: OFF | VF 3 (11) 31/08/13 13:30-14:20 | DGI (F) 21 DGI (E) 18 DGP 0,23 Ev 484 lx

figure 5-37: VF 3 (11): data and images of HDR and Evalglare (window size “L”, date “31/08”)



Shading: NO
Lighting: OFF
VF 3 (11b)
17/07/13
11:50-12:30
DGI (F) 21
DGI (E) 15
DGP 0,25
Ev 1289 lx

figure 5-38: VF 3 (11b): data and images of HDR and Evalglare (window size “XL”, date “17/07”)



Shading: NO
Lighting: OFF
VF 3 (3)
31/08/13
13:30-14:20
DGI (F) 19
DGI (E) 19
DGP 0,25
Ev 1201 lx

figure 5-39: VF 3 (3): data and images of HDR and Evalglare (window size “XL”, date “31/08”)

The figures repeat twice the same visual field and configuration of the façade. They compare the glare effects in relation to two different days of summer (17/07 and 31/08). This is the variable that this chapter pretends to highlight. Looking at the photographs, the differences are less obvious in this experiment because there are not sun patches inside the room (which clearly change their position in relation to the moment). Now, the sun patches are visible outside the room. They are reflected on Madame Tussauds' façade. Because of their size and high brightness in both sunny days, it is difficult to perceive the difference with the naked eye. The reading of the graphics will be especially helpful to clarify whether there is any change or not in the lighting conditions.

The first remark is that the values of the luminance of the background are clearly low (figure 5-40). This meeting room is clearly less illuminated than the previous (facing south). Regardless of the configuration of the façades (X or XL), the values of Lb are clearly lower. Specifically, those of the visual fields 2, 3 and 4 vary between 30 and 66 cd/m2. Instead, when the south-facing meeting room was studied considering exactly same façade, the values of Lb for all the visual fields swung between 97 and 409 cd/m2. Undoubtedly, the orientation is one of the reasons. Without the sun patches in the interior, the north-facing room is reasonably darker. In addition, the lower reflection coefficients of the finishes of this room contribute to the same effect.

In this experiment, the visual field named VF1 (figure 5-35, codes 1/5 and 9/13) is an exception. Its position could describe the visual field of a hypothetic user doing an office task close to the window. It does not correspond to the same activity of the latest visual fields, describing logical positions seating around the meeting room table. The purpose of this visual field is to contribute to understand the effects that cause high values of the glare indexes by means of comparisons. This visual field can be compared to the one named VF2 (figure 5-35, codes 2/6 and 10/14), which looks through the window in the same directions but corresponds to a position at the back of the room. Then, this visual field presents simultaneously the bright view through the window and the dark view of the interior. Meanwhile, the latest two visual fields can be compared to next two: VF3 (figure 5-35, codes 1/7 and 11/15; figures 5-36 to 5-39) and VF4 (figure 5-35, codes 4/8 and 12/16). The window is no longer in the centre of the vision. Now, the susceptible source of glare occupies lateral positions in the visual field, in which most of the pixels are related to the interior space. These two last visual fields describe similar positions, although they can be compared as they differ in the proximity to the window.

The emphasis on the directions of the vision and the positions of the glare sources within the visual field appears to be especially relevant when we analyse the results of the DGI index. Considering first the “L configuration” (figure 5-40, left hand side), the results are almost equal for VF1 and VF2 (DGI between 24 and 26). They describe a perception of glare defined as disturbing. Even if Lb and Ev are clearly higher in VF1 according to a closer position to the window, the central position of the glare source seems to be the main cause of the high DGI results in both cases.

Equally, the position is determinant when the glare sources occupy lateral positions within the visual field (VF3 and VF4). The very short lapse of time between the measurements guarantees the constancy of the daylight conditions in the space. It permits the comparisons depending on the positions (facing the window or sideways) that imply radically different DGI results. When the glare sources are visible in lateral positions within the visual field, the results are almost identical. They vary between 17 and 18 and describe situations when glare starts to be perceptible. As it has been mentioned, if we compare VF3 and VF4, a slightly different position of the glare sources could be distinguished, depending on the proximity to the window. Despite that, there is not a significant variation in the DGI results.

The previous measurements, related to the presence of the sun patches outside, validate that the observer’s position in the room might be the most decisive factor of the DGI results. The experiment searches more arguments to support this statement. Thus, it adds the comparison of two different daylighting conditions corresponding to different dates (17th of July and 31st of August) at similar hours. Despite that variable, which implies different positions of the sun, the results show a clear constancy according to the mentioned observer’s position. Only two cases (VF1 and VF4) present an almost insignificant variation of one unit.

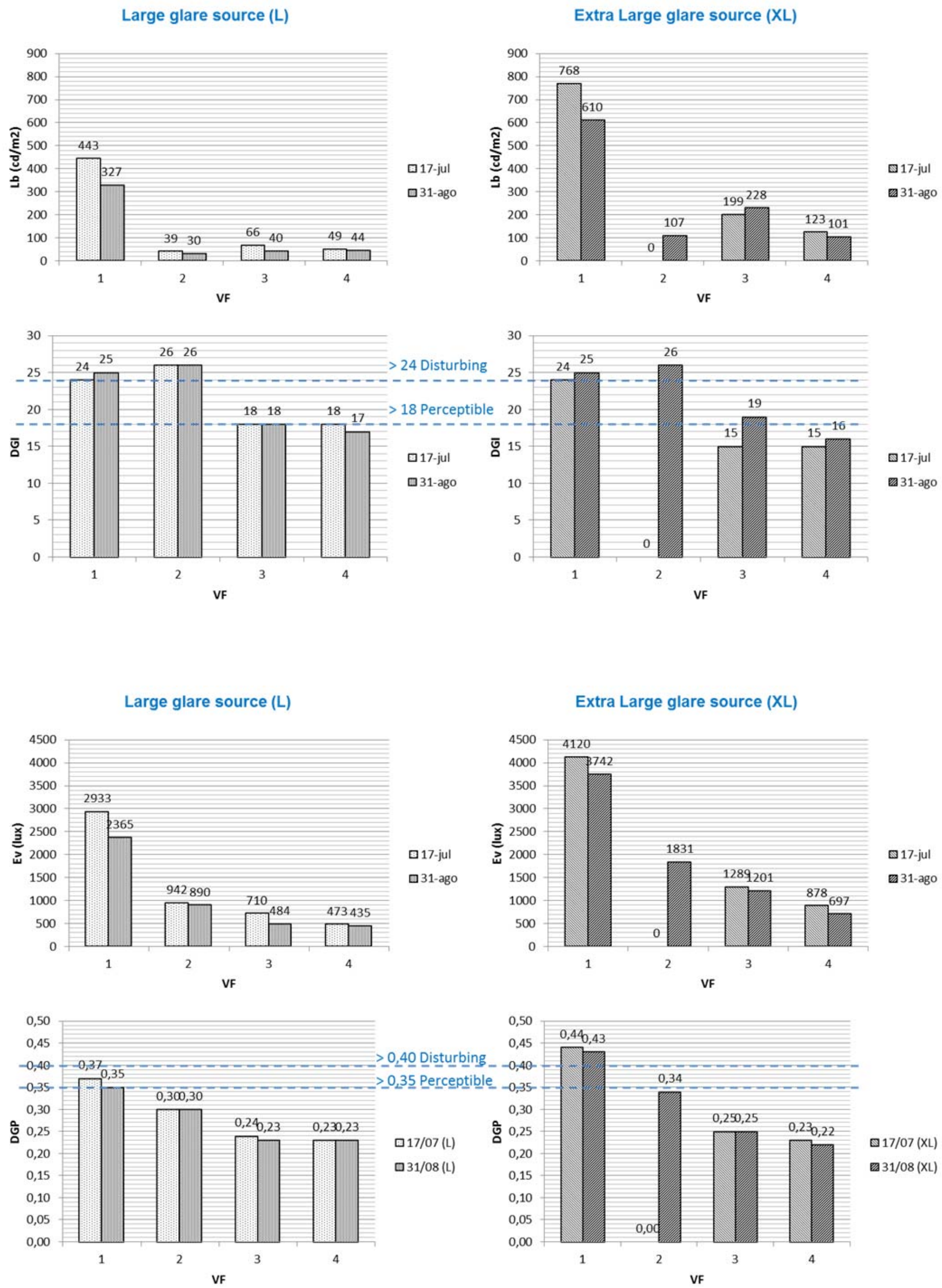


figure 5-40: Results room M327: Lb, DGI, Ev and DGP of the five VF, with two window sizes (L, XL), at two different dates (17/07, 31/08)

Similar statements could be deduced in relation to the assessment of the “XL configuration” (figure 5-40, right side). Although this experiment presents an irregularity (the measurement corresponding to VF2 was not registered on the 17th of July), it seems clear that the results of VF1 and VF2 are almost equivalent and give alert of a risk of disturbing glare. Equally, the results of VF3 and VF4 are totally different to those of VF1 and VF2. Except one case (DGI=19), the results describe perceptions that are clearly under the threshold of a perceptible glare. Again, the impact of the observer’s position (and consequently the position of the glare sources within the visual field) is so relevant that the results only present small variations according to the two different dates (17^{th} of July and 31^{st} of August).

The DGP results appear as less helpful in order to extract conclusions. As usual, the results uncover a clear dependence of the Ev value. Thus, VF1 presents the highest DGP results. The index surpasses the thresholds describing the perception of a perceptible or disturbing glare depending on the configuration of the façade (“L” or “XL”). As it occurs using the DGI index, the DGP results clearly identify a lower risk of discomfort when the sources of glare are not visible in the centre of the vision. Now, the DGP results which are related to VF3 and VF4 are notably under the limits of a perceptible glare regardless of the configuration of the façade (“L” or “XL”). The last visual field (VF2) presents more undefined results, halfway between to the lateral positions of the glare sources (VF3 and VF4) and the central positions (VF1).

Finally, the last agreement between the DGP and DGI results corresponds to their sensitivity to different daylighting conditions caused by the two different dates assessed by this experiment. Again, the DGP results do not show substantial variations and certain constancy can be affirmed in relation to the specificities of the visual fields. This constancy is even more apparent with the DGP index due to the similarities of the Ev values despite the two different dates.

Second variable: artificial light on and off – in order to minimize glare

The previous chapter (5.2.2) studied two variables of lighting in a south facing room. The first one considered two different hours in the same day. The second one studied the effects of the artificial lighting in order to balance the interior and exterior light. The present chapter also studies two variables. The first one has changed but the second one is maintained. Again, during a day with clear sky conditions, the experiment repeats the measurements considering the studied variable, turning on and then off the artificial lighting.

The experiment settled in the south facing room demonstrated that, when the sunlight illuminates the space and is responsible of sun patches close to the window, the power of the artificial lighting is insufficient to compensate the risk of imbalance of the light conditions (or glare) when the interior and exterior are simultaneously present in the visual field. Although insufficient, this effect of compensation can be slightly appreciated when the window represents a small proportion of the façade. However, it never happens when the glazing predominates in the façade. In this chapter, the present case study is useful to assess if the repercussions of the artificial lighting are equivalent in a north facing room. Apparently, their effects should be higher because the interior is clearly darker (absence of sun patches in the interior and darkness of the interior finishes) while the exterior remains bright (blue sky and sun reflected on the light-coloured façade of Madam Tussauds' Museum).

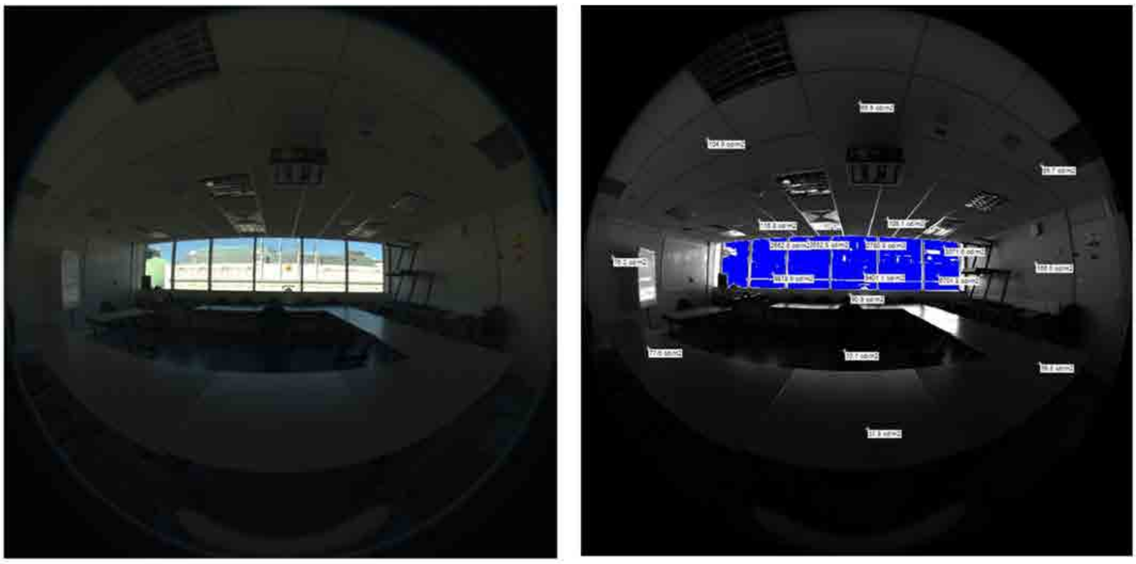
The appraisal of the next figures (5-41 to 5-44) reveals two possible effects of the artificial lighting. Firstly, the HDR photographs evidence that the artificial lighting is clearly increasing the luminances in the interior. Secondly, the Evalglare images reveal that the lamps of the artificial lighting are visible and increase the number of pixels considered as glaring. Looking at the “L” configuration (figure 5-42), the representation shows that the glaring pixels related to the artificial light are equivalent to those of the bright pixels corresponding to the view through the window. Which one of these two effects predominates? Is it the first one, improving the lighting balance? Or, is it the second one, adding bright pixels and then risk of glare? The analysis of the calculations (figure 5-45) will be necessary to conclude.

Shading: YES	Lighting: OFF	VF 2 (10) 31/08/13 13:30-14:20	DGI (F) 29 DGI (E) 26 DGP 0,30 Ev 890 lx

figure 5-41: VF 2 (10): data and images of HDR and Evalglare (window size “L”, lighting “OFF”)

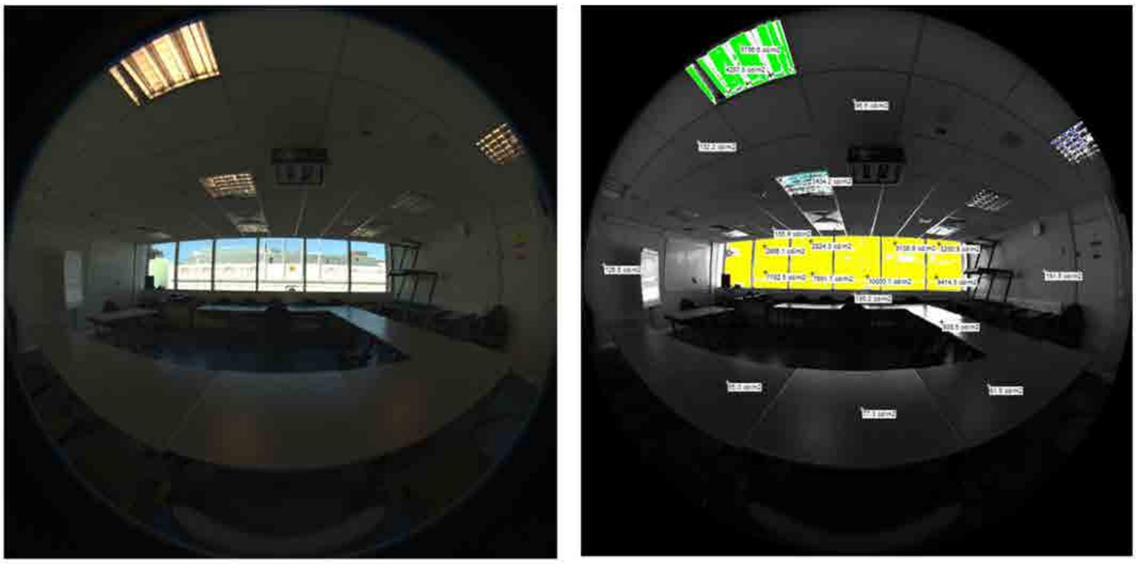
Shading: YES	Lighting: ON	VF 2 (14) 31/08/13 13:30-14:20	DGI (F) 28 DGI (E) 25 DGP 0,29 Ev 894 lx

figure 5-42: VF 2 (14): data and images of HDR and Evalglare (window size “L”, lighting “ON”)



Shading: NO | Lighting: OFF | VF 2 (2) 31/08/13 13:30-14:20 | DGI (F) 28 DGI (E) 26 DGP 0,34 Ev 1831 lx

figure 5-43: VF 2 (2): data and images of HDR and Evalglare (window size “XL”, lighting “OFF”)



Shading: NO | Lighting: ON | VF 2 (6) 31/08/13 13:30-14:20 | DGI (F) 27 DGI (E) 26 DGP 0,34 Ev 1961 lx

figure 5-44: VF 2 (6): data and images of HDR and Evalglare (window size “XL”, lighting “ON”)

Obviously, Lb and Ev are two significant parameters to describe how the lighting conditions change when the artificial lighting is turned on. It is reasonable to anticipate that both values will increase but it would be a mistake to expect certain constancy. The results of Ev are especially sensitive to the position of the camera's lens in relation to the lamps. The results of Lb are even more unpredictable. As explained, Lb is the result of a calculation in two steps. After calculating the average luminance of the scene, Lb describes the average luminance of the pixels that are excluded of the glare sources according to the predefined threshold.

Nevertheless, a global reading of the results permits to affirm that the contribution of the artificial lighting compared to daylighting power is again very low, as it happened when the south facing room was the case study. When the north façade adopts the “L” configuration, the Lb results barely increase when the artificial lighting is turned on. Equally, Ev does not register significant increases. Unexpectedly, Ev decreases slightly when VF4 is assessed. A partial reduction of the sunlight conditions is presumably the reason. This irregular situation also happens when the measurements are done considering the “XL” configuration. Three visual fields present a small reduction of Ev. However, with this configuration, all the Lb values register an increase. Only VF1 registers an insignificant reduction.

Despite the detailed values of Lb and Ev, the DGI calculations demonstrate that the artificial lighting barely contributes to rebalance the lighting conditions. Its effects are recognizable. Although new glare sources are added, the final repercussions never affect negatively. Nonetheless, the power of the artificial lighting is insufficient to improve the situations where there is an excessive contrast caused by the windows (VF1 and VF2). The reduction of the DGI results counts only one unit and glare remains disturbing. Equally, when the DGI results are lower (approximately 18 – perceptible glare), the reduction never exceeds one unit. This happens independently of the proportion of glazing in the façade (“L” or “XL” configurations). The analysis of the DGP results validates the same conclusions. When using this index, the reductions of glare represent max 0.01 units, no matters if the DGP values are high or not.

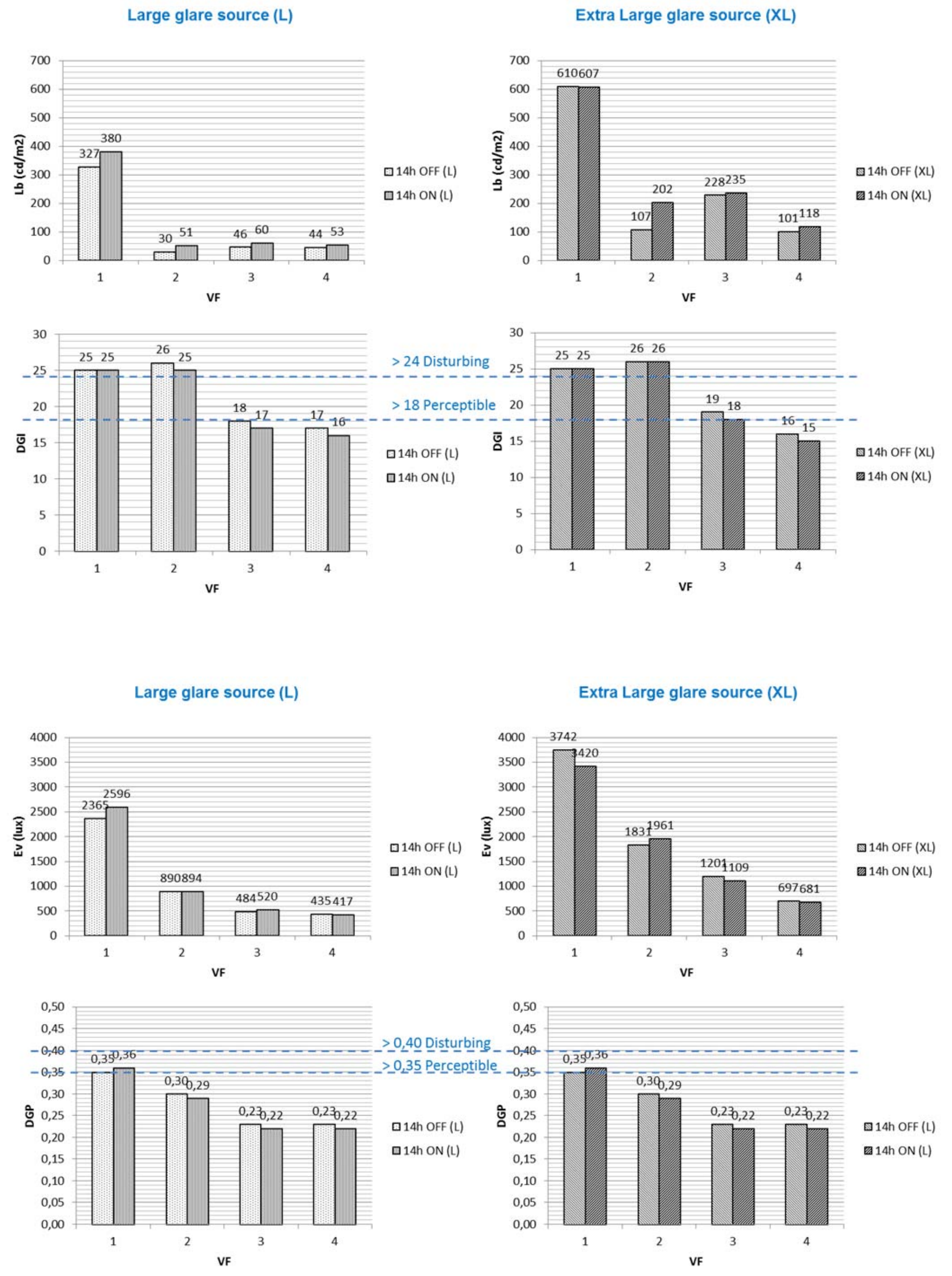


figure 5-45: Results room M327: Lb, DGI, Ev and DGP of the five VF, with two window sizes (L, XL) and two artificial lighting settings (OFF, ON)

5.2.4. Sun patches inside a west-facing meeting room

The previous chapter analyses the risk of glare in side-lit meeting rooms, under sunlight conditions, by means of experiments which took place in the interiors of a building located in London. The current chapter continues with the study of glare under sunlight conditions in meeting rooms. However, the new experiments change the location, the orientation of the interiors, the dates and the lighting control systems. They analyse the risk of glare under sunlight conditions which are presumably worse.

The new spaces belong to a building located in Barcelona. Unlike the latter two interiors of London, which compared the glare effects related to the south and north orientations, the experiments of Barcelona analyse the risk of glare in two rooms facing west. In addition, the London case studies compared different dates of summer whereas in Barcelona the dates are near to the equinox. Thus, the sunbeams are now more horizontal and the risk of glare is supposed to be higher.

In relation to the lighting control systems, the London cases studied the effects of the artificial lighting in order to rebalance imbalanced lighting situations. Two different sizes of glare sources were assessed thanks to the darkness of the shading devices. In Barcelona, due to the extreme conditions, the experiments analyse the contribution of different alternatives of standard shading devices (Danz, 1967; Dubois, 2001) in order to reduce glare.

Considering all the previous, the assessments of this chapter will be useful to find the answers to the following questions:

- Is the risk of discomfort glare higher when the sun patches are due to horizontal sunbeams?
- Consequently, are the west façades the worst in terms of discomfort glare?
- Considering the west façades, are the shading devices a solution? Or, do their surfaces create new patches of brightness which are liable to become unexpected sources of glare?

First variable: different hours – from discomfort glare to disability glare

Figure 5-46 describes the meeting room where the first experiment of this chapter takes place. The room occupies the fourth floor of School of Architecture of Barcelona. The angle of deviation of the façade from the west equals 19 degrees. Despite that deviation, the façade can be considered as west oriented. The A-A elevation shows an interior view of this façade. During the experiment, the view through the windows is mainly the view of the clear sky. The interior finishes are quite common. The walls and the ceiling are painted in white. A few paintings and a bookcase interrupt occasionally the vision of the walls. A rectangular wooden table occupies the centre of the room. It is light-coloured and the reflection of the light on it is partially specular due to the varnish. The figure 5-46 also includes the position of the five visual fields which are analysed.

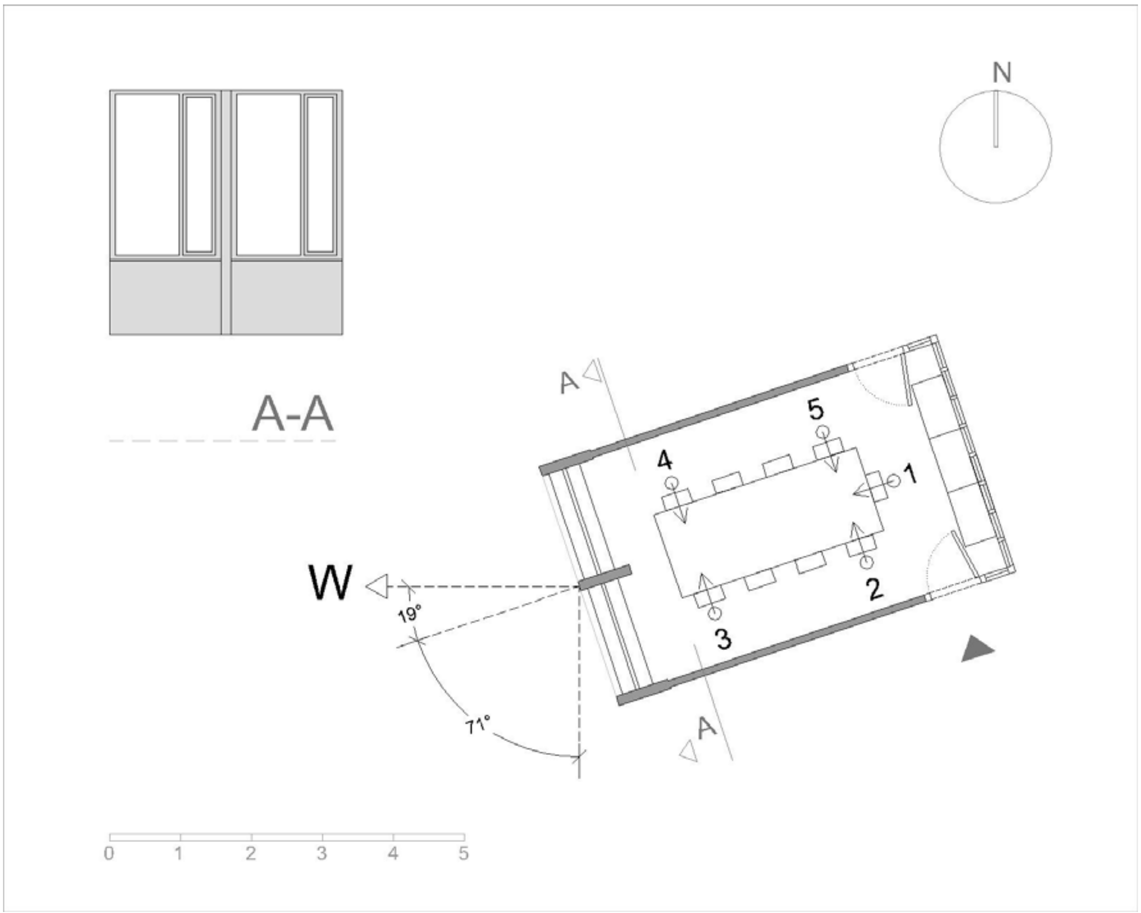
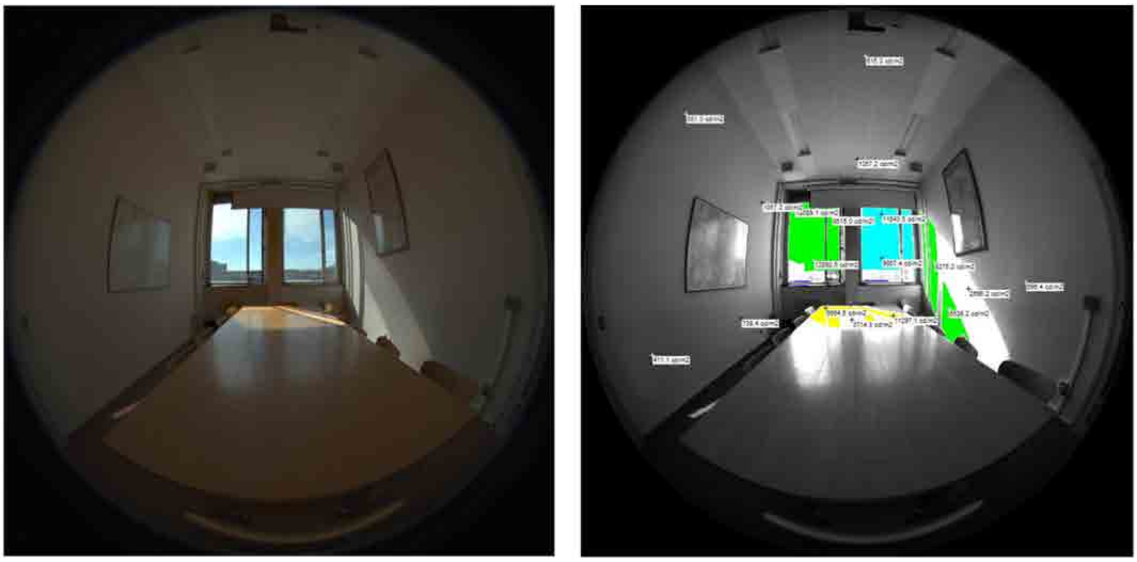


figure 5-46: Room URB and five VF: comparison of the glare effects in a west facing space, depending on the user's position and hour of the day



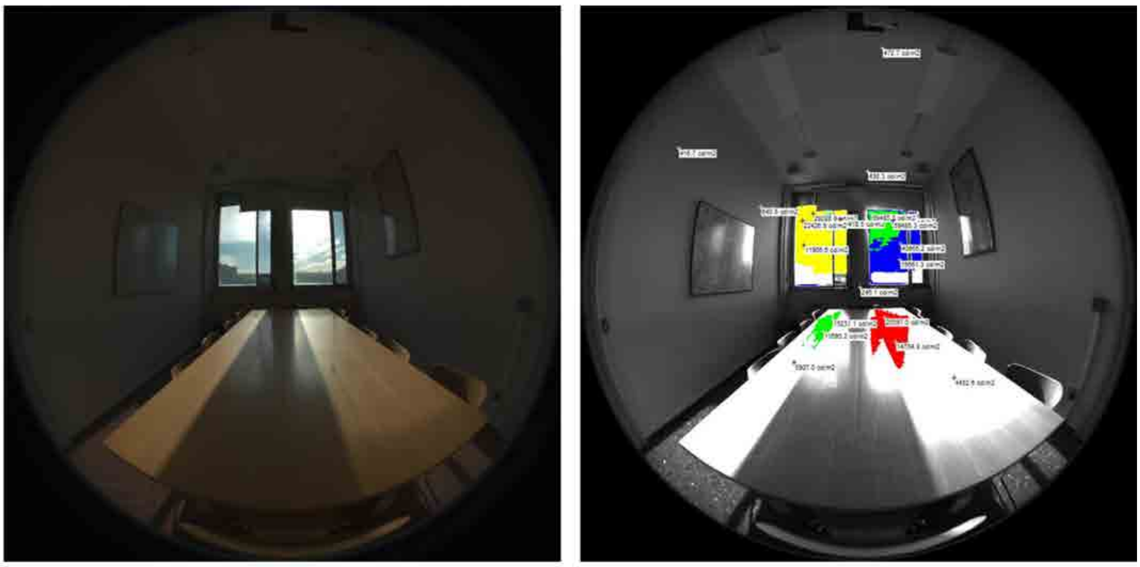
Shading: NO

Lighting: OFF

VF 1 (13)
20/09/13
16:00-16:30
(-26,39)

DGI (E) 25
DGP 0,48
Ev 4903 lx
Lb 767 cd/m^2

figure 5-47: VF 1 (13): data and images of HDR and Evalglare (hour: 16:00)



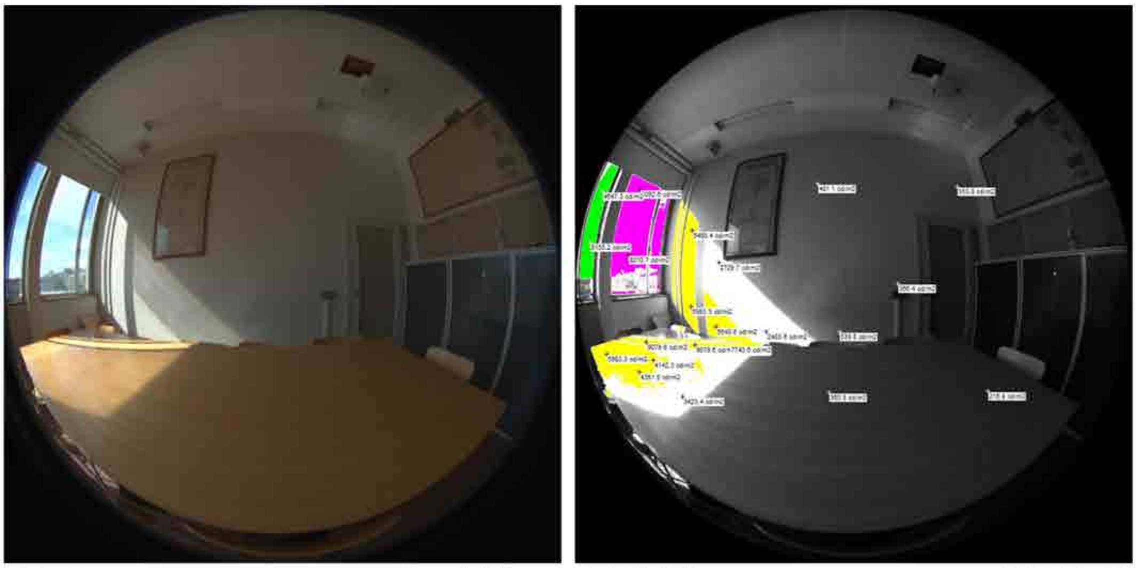
Shading: NO

Lighting: OFF

VF 1 (33)
20/09/13
18:00-18:17
(-1, 20)

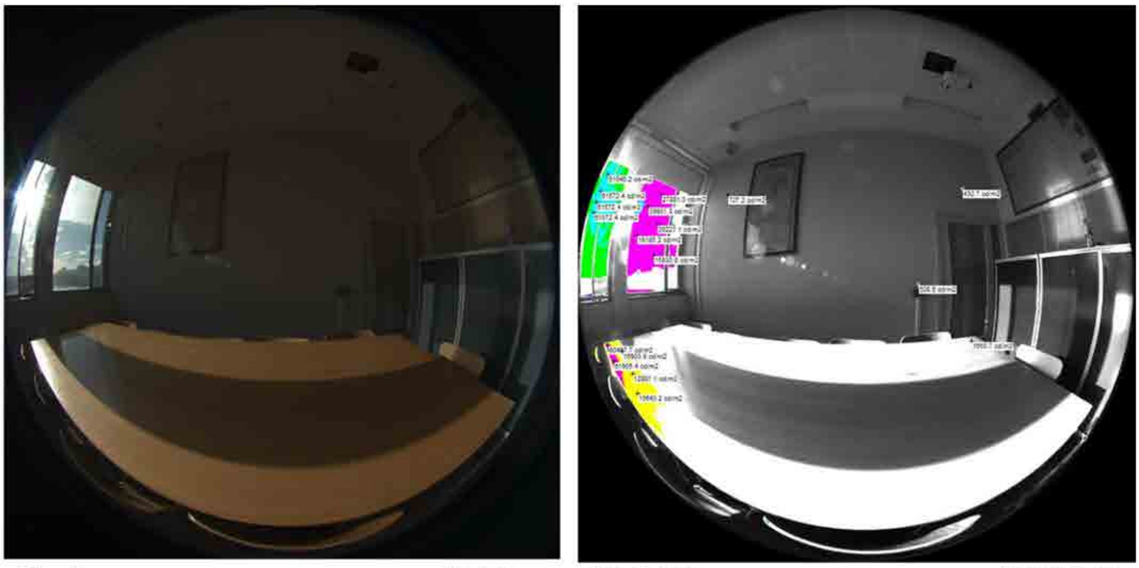
DGI (E) 29
DGP 0,73
Ev 8792 lx
Lb 989 cd/m^2

figure 5-48: VF 1 (13): data and images of HDR and Evalglare (hour: 18:00)



Shading: NO | Lighting: OFF | VF 2 (14) 20/09/13 16:00-16:30 (-26,39) | DGI (E) 15 DGP 0,31 Ev 2363 lx Lb 549 cd/m²

figure 5-49: VF 2 (14): data and images of HDR and Evalglare (hour: 16:00)

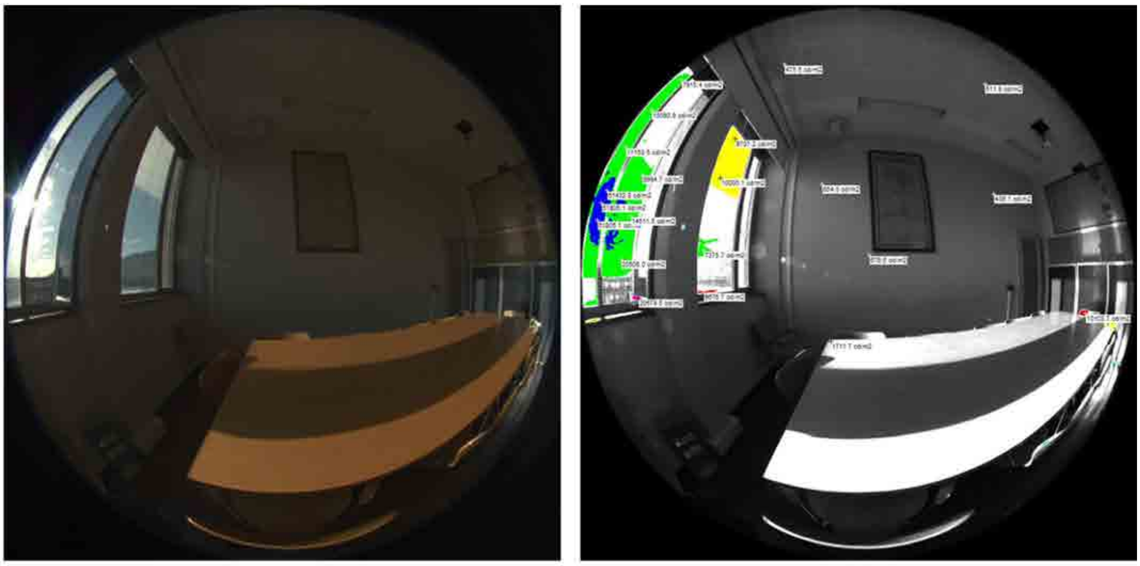


Shading: NO | Lighting: OFF | VF 2 (34) 20/09/13 18:00-18:17 (-1, 20) | DGI (E) 19 DGP 0,41 Ev 4016 lx Lb 954 cd/m²

figure 5-50: VF 2 (34): data and images of HDR and Evalglare (hour: 18:00)

Shading:	Lighting:	VF 3 (15)	DGI (E) 8
NO	OFF	20/09/13	DGP 0,49
		16:00-16:30	Ev 5549 lx
		(-26,39)	Lb 1722 cd/m²

figure 5-51: VF 3 (15): data and images of HDR and Evalglare (hour: 16:00)



Shading:	Lighting:	VF 3 (35)	DGI (E) 15
NO	OFF	20/09/13	DGP 0,34
		18:00-18:17	Ev 2995 lx
		(-1, 20)	Lb 740 cd/m²

figure 5-52: VF 3 (35): data and images of HDR and Evalglare (hour: 18:00)

Shading: NO

Lighting: OFF

VF 4 (16)
20/09/13
16:00-16:30
(-26,39)

DGI (E) 15
DGP 0,49
Ev 5543 lx
Lb 1194 cd/m²

figure 5-53: VF 4 (16): data and images of HDR and Evalglare (hour: 16:00)

Shading: NO

Lighting: OFF

VF 4 (36)
20/09/13
18:00-18:17
(-1, 20)

DGI (E) 13
DGP 0,38
Ev 3670 lx
Lb 879 cd/m²

figure 5-54: VF 4 (36): data and images of HDR and Evalglare (hour: 18:00)

Shading: NO	Lighting: OFF	VF 5 (17) 20/09/13 16:00-16:30 (-26,39)	DGI (E) 18 DGP 0,29 Ev 1926 lx Lb 385 cd/m^2

figure 5-55: VF 5 (17): data and images of HDR and Evalglare (hour: 16:00)

Shading: NO	Lighting: OFF	VF 5 (37) 20/09/13 18:00-18:17 (-1, 20)	DGI (E) 16 DGP 0,37 Ev 3459 lx Lb 910 cd/m^2

figure 5-56: VF 5 (37): data and images of HDR and Evalglare (hour: 18:00)

The previous figures (from 5-47 to 5-56) describe the five visual fields. On the left side appears the HDR image. On the right side, an Evalglare image identifies the pixels that are considered as potential glare sources. Beneath these two images, the most relevant data are specified. The position of the sun is identified in parentheses. The first value describes the relative azimuth. That is to say that the value equals zero when sun's azimuth is exactly in perpendicular to the façade. From this reference, a convention states that the sunbeams come from the left (south) if the angle is negative and, contrarily, from the right (north) if the angle is positive. After the comma, the second value in parentheses indicates the angle of elevation above the horizon.

Each one of the previous pages compares the sunlight repercussions in relation to the same visual field, considering the first variable of this experiment, which is the analysis of different hours of the afternoon. Although these pages only show the comparison of two different hours (4 pm and 6 pm), the experiment considers eight different hours. It starts at 1.30 pm and the measurements are repeated every hour, until 3 pm. Since that time, the measurements are repeated every 30 min because the elevation of the sun changes rapidly. This last procedure ends at 6 pm.

The two images are useful to visualize how different are the sun patches at 4 pm and 6 pm. Their reflection on the table and the lateral walls changes notably. The observation of these images could lead to misleading in relation to the vision through the window. In every image, the top vision through the two windows seems to describe portions of sky with clouds. However, these were not the sky conditions. Almost all the afternoon the sky was clear and it made possible the comparison of the glare effects considering the five visual fields. The reason of the misunderstanding is that the exterior top part of the window is not clean due to the difficult accessibility and the limitations of the contract of maintenance. Thus, there is a diffuse transmission of light through the dust that reminds the cloudy conditions.

Finally, there is a last comment in relation to the windows. The AA elevation depicts the design of the façade (figure 5-46). Two identical windows compose this façade. Each one combines fixed and openable parts. The fixed part is the biggest and the one which was dirty on the top. The experiment proposes to consider the effects of the glazing. That is why it combines two different positions of the two openable parts:

opened on the left and closed on the right. However, the experiment shows that the impact of the glazing is inconspicuous because it is a single glazed window with high transmittance.

The graphs presented on figure 5-58 permit the study of the combined effects of the sun patches and the view through the windows. The graphs make possible the analysis of the risk of glare during all the afternoon thanks to the calculated glare indexes. Figure 5-58 presents first the DGI results. Then, the risk of glare is also categorized by the DGP results. Finally, the luminance of the background (Lb) and the illuminance on the lens (Ev) help to understand the results of the glare indexes. The results of the five visual fields are represented by vertical bars with different colours. The two first assessments (13:30 and 14:30 pm) do not consider VF4 and VF5. Figure 5-57 describes the sun patches reflected on the interior surfaces in a hypothetic situation without furniture. This figure is helpful to understand the results of Lb and Ev and, in consequence, the results of the glare indexes.

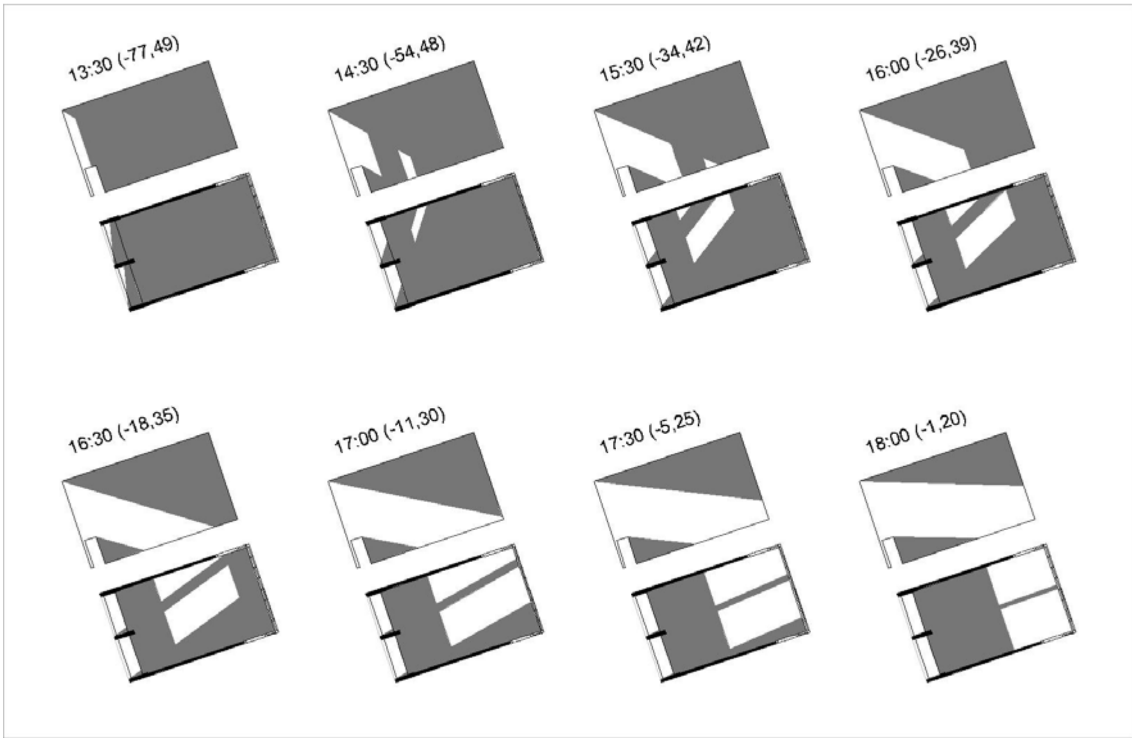


figure 5-57: Light and shadows according to different hours, room URB (plans and sections)

figure 5-58: Results room URB: DGI, DGP, Lb and Ev of the five VF, at eight different hours of the afternoon

In relation to the DGI results, the first remark points the degree of constancy of the results over time (during an afternoon, one day before the equinox). Now, in this west facing room, the results are more changeable. Undoubtedly, the rapidity of the sun's movement is the cause. Three visual fields (VF1, 2 and 3) are more susceptible to these changes. Table 2 permits to quantify the variation. The results vary 9 units (31-22) for VF1, 7 units (19-12) for VF2 and 14 units (21-7) for VF3. These three visual fields perceive how the sun patches change on the table and lateral wall. The figure 5-57 evidences the magnitude of the variations of the sun patches on the lateral wall. Instead, there is more constancy in the results of the last two visual fields. They vary 4 units for VF4 (17-13) and VF5 (20-16). These visual fields also perceive how the sun patches change on the table. However, they face a lateral wall with less lighting variation. The sun patches are not reflected on this wall. Its luminances are lower and they are always included in the luminance of the background (Lb).

	DGI				
TIME	**VF1**	**VF2**	**VF3**	**VF4**	**VF5**
1330 (-77,49)	22	12	16		
1430 (-54,48)	22	12	21		
1530 (-34,42)	23	16	14	17	16
1600 (-26,39)	25	15	8	15	18
1630 (-18,35)	26	14	7	15	20
1700 (-11,30)	28	13	10	14	16
1730 (-5,25)	31	17	13	14	19
1800 (-1,20)	29	19	15	13	16

table 5-2: DGI results in relation to the 5 visual fields and the 8 hours (20-Sep), room URB

As it happened in the previous experiments (south and north facing rooms), the observer's position appears has one the most relevant factors. In accordance with that, VF1 accounts the highest DGI results during all the afternoon. Its eight results are superior to 18 (perceptible glare). Five of them exceed 24 (disturbing glare) and just one equals 31 (intolerable glare). Figure 5-58 shows that the values of Ev are very high in that position. Thus, it describes a scene where Lb increases and the luminance of the glare sources becomes extreme. The situation is radically different for the other four visual fields. Their results never reach 24 (disturbing glare). Considering all the visual fields, only five exceptions register DGI results exceeding 18 (perceptible glare): VF2 at 18:00, VF3 at 14:30 and VF5 at 16:00, 16:30 and 17:30.

The comparison of the DGI values of the visual fields which share the same proximity to the window but face different lateral walls is also relevant. That comparison is useful to assess the influence of the sunlight reflected on the lateral walls. VF2 and VF5 are both at the back of the room. VF5 faces the lateral wall in shadow. Its DGI values are normally higher than those of VF2. The next sequence shows the results of the differences (VF5-VF2) according to the hours: ?, ?, =, +3, +6, + 3, +2, -3. Surprisingly, the absence of the sun patches on the wall in VF5 implies a higher risk of glare. Figure 5-58 shows the reason. The values of Lb are always low for VF5. There is an imbalanced situation between the darkness of the interior and the brightness of the window and the reflected sun patches on the table. Hence, it is possible to affirm that the sun patches on the lateral wall, which are visible from VF2, contribute positively and rebalance the light contrast between the interior and exterior. The same deduction is possible comparing the results of VF3 and VF4. The latter visualizes the wall without sun patches. Its results are the worst. Again, the next sequence shows the results of the differences (VF4-VF3) according to the hours: ?, ?, +3, +7, +8, +4, +1, -2. The highest differences appear when the Lb values of VF4 are clearly lower than the Lb values of VF3. Again, the sun patches on the lateral wall are responsible of the increase the Lb values of VF3 and the reduction of the risk of glare.

The comparison of the results of the visual fields that are in the same side of the table is interesting in order to assess the influence of the proximity to the window. Two comparisons are possible: VF2 versus VF3 and VF4 versus VF5. The two first visual fields face the lateral wall that reflects the sunbeams. At 13:30 and 14:30, the DGI results are higher for VF3 (+4, +7). The solar access is moderate and does not raise substantially Lb. Thus, the proximity to the glare sources motivates the higher results near the window (VF3). Since 15:30, progressively, the solar access invades the room. VF3 perceives a very bright scene and only a small number of pixels are considered as glare source (figure 5-51). VF2 visualizes a darker interior confronted to the high brightness of the sky and the sun patches on the wall and table (figure 5-49). The particularities of these two visual fields explain the higher DGI results for VF2 (+2, +7, +7 +3, +4, +4). The second pair of visual fields (VF4 and VF5) faces the lateral wall that never reflects the sunbeams. Nevertheless, the situation is similar. Far from the window, since 16:00, VF5 presents higher DGI results (+3, +5, +2, +5, +3) as it faces a dark interior confronted to the high brightness of the sky and the sun patches on the table (figure 5-55). Before the progression of the solar access inside the room, at 15:30, the situation is different and the DGI result is slightly higher for VF4 (+1). A revision in detail of all the results related to VF4, which are calculated by the script, shows that Lav is lower at 15:30 if compared with Lav at 16:00. Thus, Lb is also lower and more pixels are considered as source of glare. These combinations explain why the DGI result for VF4 is 2 units higher at 15:30. Conversely, the same kind of combinations motivates that the DGI result for VF5 is 2 units lower at 15:30.

After studying the DGI results, it is handy to analyse the DGP results (figure 5-58 and table 5-3) with the same procedure. Then, the comparison of the conclusions with the two indexes will be possible. All the scenes of the current experiment present a remarkably high brightness. The lowest value of Ev is 759 lx, the highest is 14345 lx. Under these daylighting conditions, the DGP results are supposed to be reliable (Wienold, 2009a). Since the DGP is clearly dependent index value of Ev, it is advisable to take into account the values of Ev for a better understanding of the DGP results.

	DGP				
TIME	**VF1**	**VF2**	**VF3**	**VF4**	**VF5**
1330 (-77,49)	0,30	0,21	0,27		
1430 (-54,48)	0,32	0,23	0,39		
1530 (-34,42)	0,40	0,29	0,49	0,47	0,29
1600 (-26,39)	0,48	0,31	0,49	0,49	0,29
1630 (-18,35)	0,57	0,36	0,47	0,51	0,37
1700 (-11,30)	0,80	0,42	0,44	0,42	0,28
1730 (-5,25)	1,00	0,41	0,37	0,41	0,34
1800 (-1,20)	0,73	0,41	0,34	0,38	0,37

table 5-3: DGP results in relation to the 5 visual fields and the 8 hours (20-Sep), room URB

Following the steps used for the discussion of the DGI results, the first task is to verify the constancy of the DGP results along the afternoon. Previously, the DGI results described two possible situations: changeability or constancy. Now, in relation to the DGP results, it is more convenient to add an intermediate situation. Thereby, the correspondence between those three situations and the five visual fields would be: changeability for VF1 (1-0.3=0.7), intermediate for VF2 (0.42-0.21=0.21) and VF3 (0.49-0.27=0.22), and constancy for VF4 (0.51-0.38=0.13) and VF5 (0.37-0.28=0.09).

The next remarks pretend to recognise the risk of glare in relation to the five visual fields. According to the DGI results, the risk was only worrying for VF1. The DGP results also identify VF1 as the visual field where the risk of glare is the highest. From a total of eight results, five of them are clearly superior to 0.45 (intolerable glare) and one exceeds 0.4 (disturbing glare). However, the DGP results add two other visual fields (VF3 and VF4 – the nearest to the window) where glare provokes discomfort. Their results are quite equivalent: for both three results are superior to 0.45 (intolerable glare); one result for VF3 and two results for VF4 exceed 0.4 (disturbing glare); two results for VF3 and one result for VF4 surpass 0.35 (perceptible glare). The same DGP results identify an intermediate risk of glare for VF2 (one result over 0.4 and three results over 0.35). Finally, the risk of glare is negligible for VF5 (only two results over 0.35 and none over 0.4).

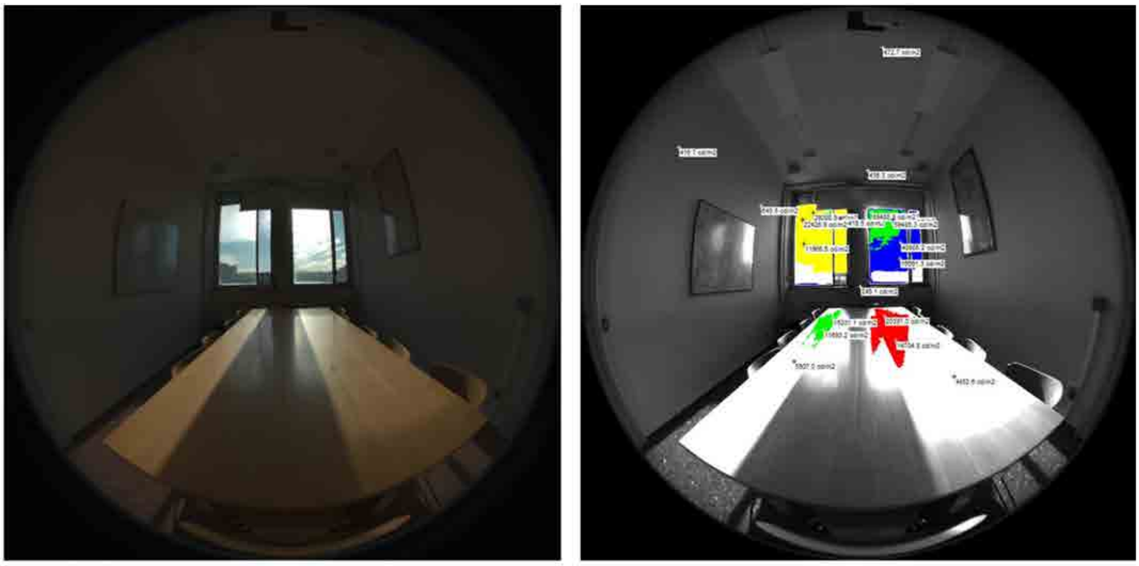
Finally, the comparison of the DGP results of the visual fields looking in parallel to the windows also shows differences in relation to the DGI results. Firstly, the comparison of the DGP results of VF2 versus VF5 and VF3 versus VF4, which tests the effects of the sun patches on the lateral walls, presents a lower sensitivity to the differences of the scenarios of lighting. The DGP index is clearly dependent on Ev. Instead, this index does not evidence a reaction to the different values of Lb caused by the reflection of sunlight. If we compare VF2 to VF5 or VF3 to VF4, the DGP differences due to the sunlight reflections on the walls hardly surpass 0.04, no matter the hour of the afternoon. Only in two cases the DGP result for VF2 is clearly higher to the result for VF5 (0.14 at 17 pm and 0.7 at 17:30 pm) due to the substantial different values of Ev. Two possible reasons argue the higher value of Ev in VF2: firstly, the vision of the sunlight reflection on the lateral wall; secondly, the vision of the sun's halo in the sky.

The second comparison regarding the visual fields in parallel to the window, studies the repercussions of the proximity to the window. The analysis of the DGI values argued that, when there is a clear presence of the sun patches close to the window, the risk of glare is lower for a visual field in that position - because there is more balance between the interior and exterior light conditions - than for a visual field at the back of the room. The size of the glare sources appeared as less important. The DGP values contradict that theory. The DGP values are always higher in the positions near to the window because the Ev value is higher there. Again, according to the DGP index, the experience of glare is more related to the idea of an excessive quantity of light rather than the idea of contrast.

Second variable: effects of the roller shutter

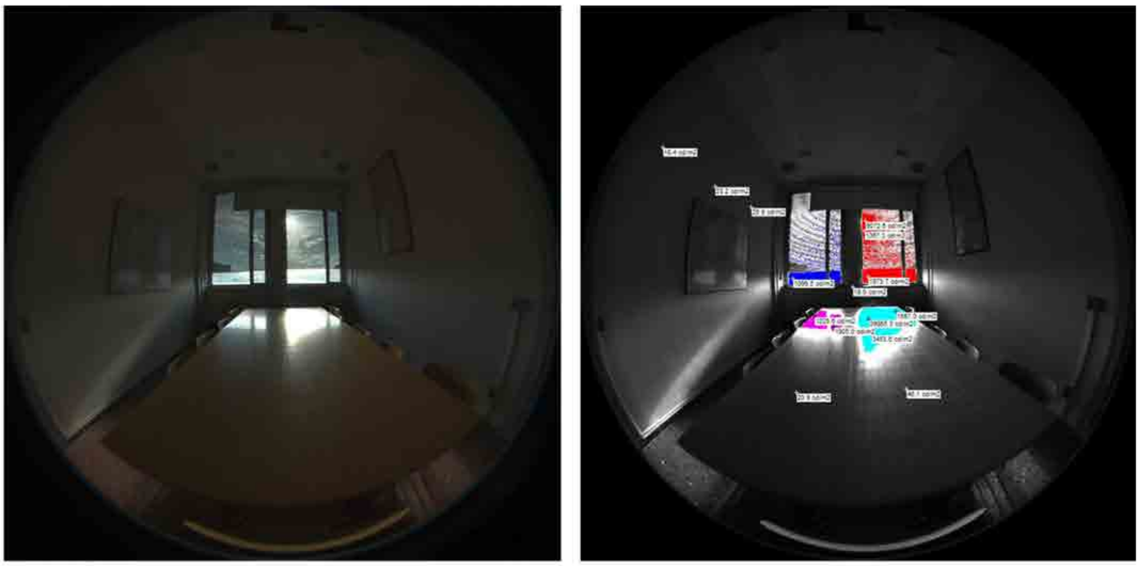
The previous room (named URB) offers the option of two roller shutters on the outside of the two windows. Typically the functions of a roller shutter are to reduce heat loss at night in winter, ensure the users' privacy and regulate the access of radiation, i.e. its heat gains and contribution to the daylighting of the rooms. The current building is the School of Architecture of Barcelona. Except the top floor, the other six floors of the building use these roller shutters. Behind, the spaces are mainly used as classrooms (east façade), offices and meeting rooms (west façade). The daily use of these spaces implies that, most of the time, the usage of the roller shutters is restricted to the last function of the previous list, i.e. the control of radiation (heat gains and daylight access). However, the effectiveness of its operation is questionable. Very often, the users of the west façade decide to keep the shutters down and work with artificial lighting when the daylight is available. Using the experimental methodology, it is useful to assess the repercussion of these roller shutters in terms of glare.

The experiment tests the use of the roller shutters facing the annoying horizontal sunbeams. It starts at 18:00 (figure 5-59), without using the shutters and analyses the repercussions for the previous five visual fields (figure 5-46). At that time the relative sun's azimuth is -1º (almost perpendicular to the façade) and the elevation above the horizon is 20º. Seventeen minutes later, after assessing the five visual fields, the measurements are repeated with another position of the roller shutter (figure 5-60). The sun is almost at the same position (5º, 16º). This new position of the shutter hides the sun and its hallo. A portion of view through the window is still visible. Depending on the task, the amount of daylight is still sufficient. Ev equals 611 lx at the back of the room, for VF1. The reduction using the shutter is drastic. Without the shutter, seventeen minutes before, the value of Ev in the same position was 8792 lx (figure 5-61). Surely, the presence of the roller shutter is the main reason of the reduction. Moreover, the movement of the sun approaching the horizon contributes slightly to this reduction.



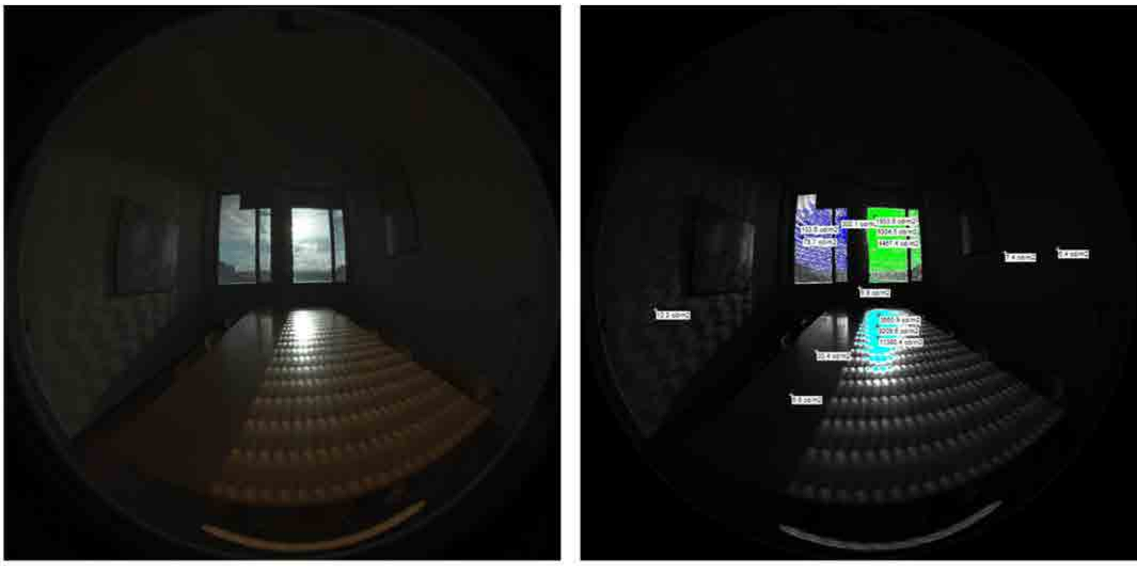
Shading: NO	Lighting: OFF	VF 1 (33) 20/09/13 18:00-18:17 (-1, 20)	DGI (E) 29 DGP 0,73 Ev 8792 lx Lb 989 cd/m²

figure 5-59: VF 1 (33): data and images of HDR and Evalglare (roller shutter: NO)



Shading: YES-PARTLY	Lighting: OFF	VF 1 (39) 20/09/13 18:17-18:29 (+4,16)	DGI (E) 26 DGP 0,29 Ev 611 lx Lb 42 cd/m²

figure 5-60: VF 1 (39): data and images of HDR and Evalglare (roller shutter: PARTLY)



Shading: YES-TOTALLY | Lighting: OFF

VF 1 (44)
20/09/13
18:29-18:38
(+6,14)

DGI (E) 25
DGP 0,26
Ev 388 lx
Lb 19 cd/m²

figure 5-61: VF 1 (44): data and images of HDR and Evalglare (roller shutter: TOTALLY)

After twelve minutes, the third position of the roller shutter follows the previous (figure 5-61). Now the roller shutter is totally down. However, light crosses the small holes between the slats and a certain view of the exterior is still possible. The sunlight is also reflected on the table. Specifically the first visual field (VF1) accounts a notable illuminance (Ev = 388 lx) in contrast to the general darkness of the interior surfaces (Lb=19 cd/m2). It will not be the same for the remaining visual fields (VF2-5). The graphs of figure 5-62 are illustrative of the last comment. They also contribute to determine the impact on glare of the three different positions of the roller shutter.

Starting with the DGI results, it is surprising to discover that the results are similar for the two first positions of the roller shutter. It happens even if the daylight conditions change clearly. Lb and Ev decrease drastically with the roller shutter. However, the combination of their effects in the formulation does not change the DGI results as drastically. Two different repercussions are recognizable. The frontal view towards the window (VF1) reduces its glare index from 29 to 26, but the result still corresponds to a disturbing perception. Conversely, the lateral views maintain or, surprisingly, increase their DGI because of a higher contrast between the interior and exterior: VF2 (from 19 to 21), VF3 (always 15), VF4 (from 13 to 17) and VF5 (from 16 to 17).

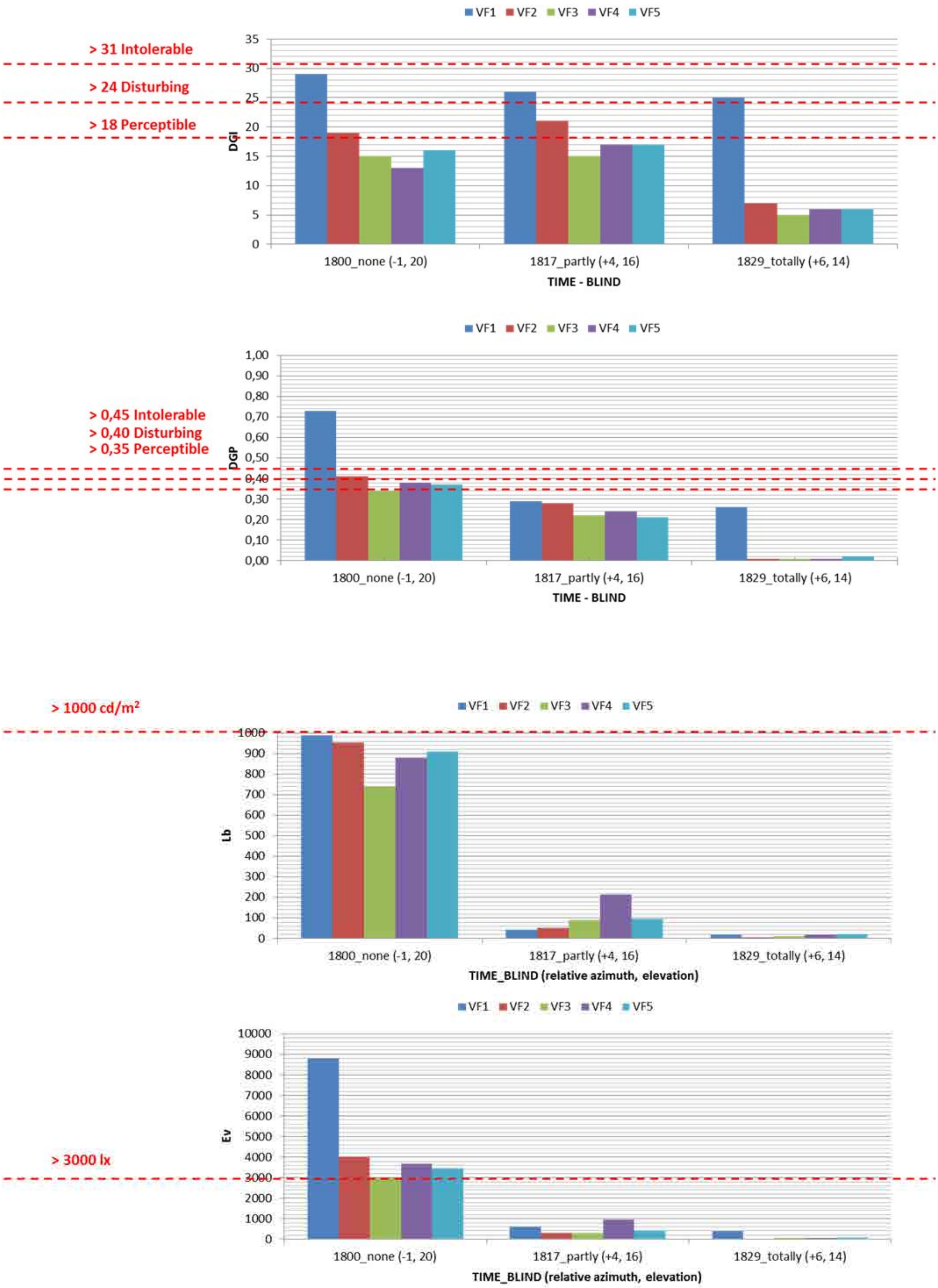


figure 5-62: Results room URB: DGI, DGP, Lb and Ev of the five VF, comparing three different positions of the roller shutter

When the roller shutter shifts from the second position (partially closed) to the third position (totally closed), the impact on the frontal view towards the window (VF1) also differs from the rest. The reduction of its DGI result is very small (from 26 to 25) whereas the results corresponding to the other visual fields experiment big reductions: VF2 (from 21 to 7), VF3 (from 15 to 5), VF4 (from 17 to 6) and VF5 (from 17 to 6). Obviously, under these light conditions, the discussion related to comfort regarding sunlight and glare is less relevant because of the amount of light, which is insufficient to develop an office task. Then, the artificial lighting would be necessary and it would become the main source of light.

The analysis is different if we consider the DGP results. When the roller shutter shifts from the first position (totally open) to the second position (partially closed), all the DGP results diminish strongly. Apparently, glare would not be perceptible for none of the visual fields. However, the reaction of DGP index is similar to that of the DGI index when the roller shutter shifts from the second position (partially closed) to the third position (totally closed). The DGP result of VF1 does not change while the results corresponding to the other visual fields are practically equal to 0.

In conclusion, the bad properties of the roller shutters as shading device justifies the reaction that was mentioned at the beginning of this chapter: the users close the roller shutters and do their work under artificial light conditions during all the afternoon. This nonsense is even more worrying as it happens in the interior spaces of a School of Architecture.

5.2.5. Sun patches on the façade of a west-facing meeting room

The previous experiments consider three side-lit meeting rooms which are exposed to different sunlight conditions due to their orientations. The first experiment starts with a south-facing room where the sun patches are reflected near to the window because of the high elevation of the sun. After, a north-facing room presents the risk of glare due to the high contrast between the darkness of the interior and the brightness of the sun patches that are reflected outside the room, on a bright façade. Finally, the third side-lit room is west oriented. Around the equinox, during approximately three hours, the sun's elevation is low and provokes sun patches in the deepest parts of the room. However, if the DGI index is considered, the risk of discomfort glare would only exist for frontal views towards the window.

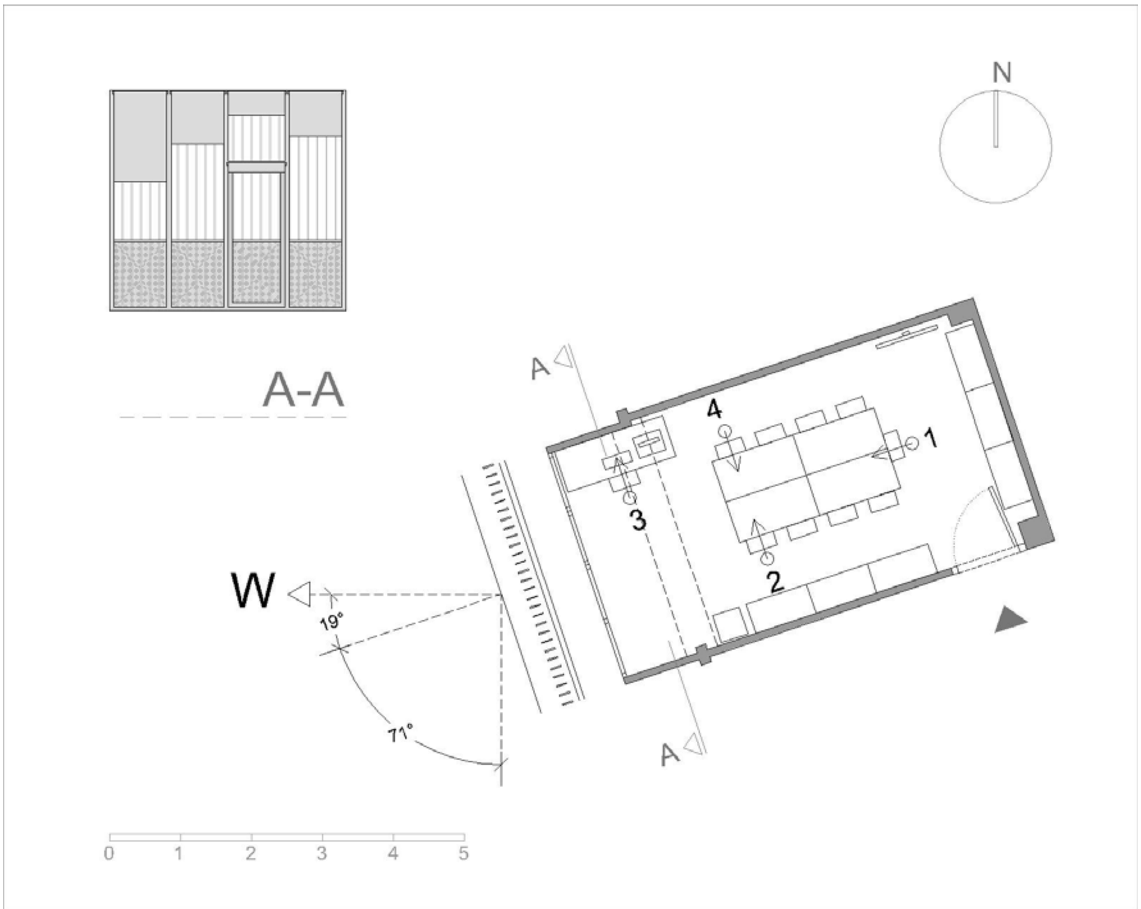


figure 5-63: Room CiS and four VF: comparison of the glare effects in a west facing space, depending on the user's position, hour of day and positions of the vertical slats

Beyond the DGI results, the shading devices are recommended for the west-facing rooms due to other types of glare (disability glare or veiling reflections). The current experiment assesses the repercussions of the shading devices in terms of discomfort glare. These devices reduce the presence of direct solar radiation in the interior. However, this radiation becomes reflected diffuse radiation when there is a reflection on a slat, or transmitted diffuse radiation when there is a transmission through a roller screen. The current experiment assesses these two cases that are identified as a third casuistry that considers the presence of the sun patches on the façade's surfaces.

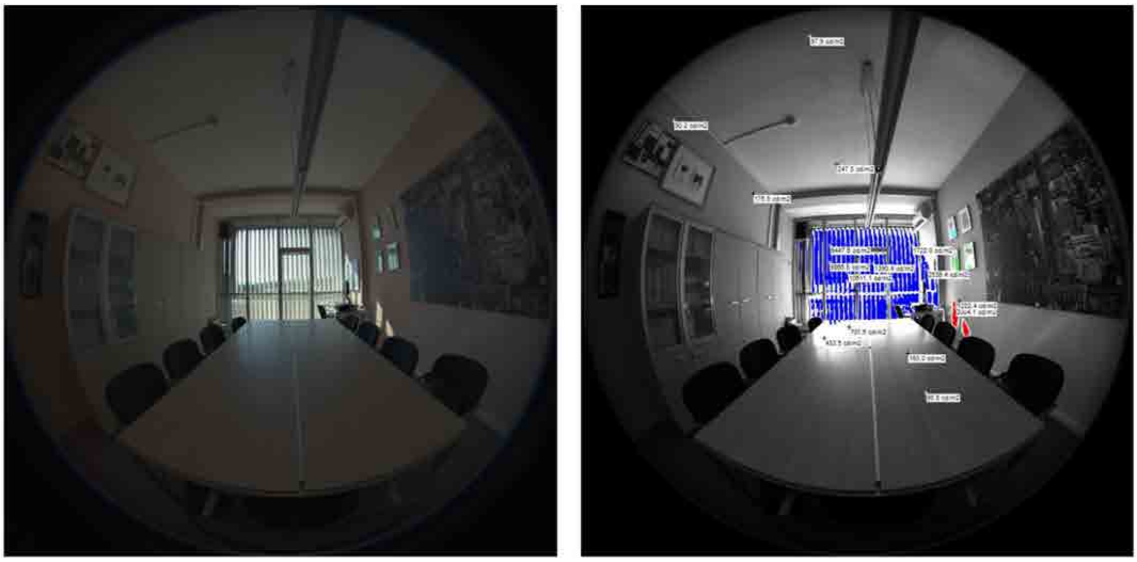
The room where the experiment takes place is located at the 7th floor of the School of Architecture of Barcelona (figure 5-63). It is the same building and the same west façade where the previous experiment took place. However, the design of the façade of this last floor is different for aesthetic reasons. Its exterior view is composed by a continuous repetition of vertical slats that give the protection against the sunbeams. Behind them, there is a narrow balcony and a totally glazed façade. Specifically, this experimental room adds a second shading device, which is an interior roller screen.

The experiment studies the impact on glare of different positions of the vertical slat (first variable) and the roller screen (second variable). As in the previous experiments, the procedure studies the glare effects considering different visual fields. The first visual field faces the view towards the window in perpendicular. The second visual field and the third correspond to visions in parallel to the window, looking at opposite lateral walls, which are under different lighting conditions due to the sun’s position and the elements of furniture. This experiment adds a fourth visual field which was not considered in the previous case studies. It recreates the hypothetical position of a horizontal view looking at a computer’s screen next to a lateral wall of the room. This position is quite common in small office rooms. Its study is especially relevant for the west-facing rooms, where the horizontal sunbeams are reflected on these lateral walls.

Finally, the last particularity of the current experiment is the existence of more diversity in the decoration. Besides the wooden meeting table (light brown), other elements are superimposed to the walls (light pink). Figure 5-64 shows these elements, basically, a wooden bookcase (light brown), several pictures and a central big photograph with dark colours.

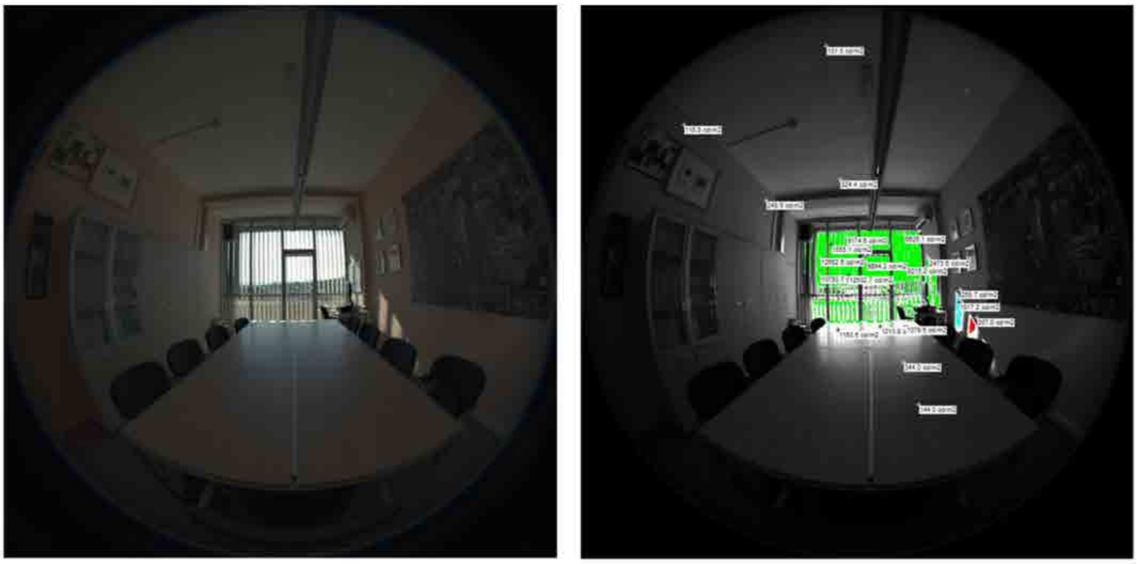
First variable: different hours and positions of the vertical slats

The previous experiment took place in the room named URB of the third floor during the afternoon of the 20th of September. The current experiment also occurred during the afternoon hours of a day close to the equinox, the 23rd of the same month. The room, named CiS, belongs to the same west façade of the same building. In both experiments, the view through the window is a big proportion of blue sky above a backlit landscape. Consequently, both experiments compare similar sunlight conditions but using different shading devices. Due to the existence of horizontal sunbeams, the vertical slats of the current experiment are a priori identified as more convenient for this west orientation than the roller shutter. Three positions of these vertical slats in relation to two different hours are the first variable of this experiment in the room named CiS. First, the vertical slats are turned 45 degrees to the left. Figure 5-64 describes VF1 under these conditions. Figure 5-67 represents VF2 under the same conditions. The next position is with the slats in perpendicular to the façade (figures 5-65 and 5-68) and the last one is with the slats turned 45 degrees to the right (figures 5-66 and 5-69). Firstly, these three positions are tested between 16:30 pm and 16:55 when the sun's azimuth varies between -19 and -13 and its elevation changes from +33 to +29.



Shading: SLAT-LEFT	Lighting: OFF	VF 1 (1) 25/09/13 16:30-16:40 (-19,33)	DGI (E) 23 DGP 0,29 Ev 1109 lx Lb 146 cd/m^2

figure 5-64: VF 1 (1): data and images of HDR and Evalglare (SLAT-LEFT)

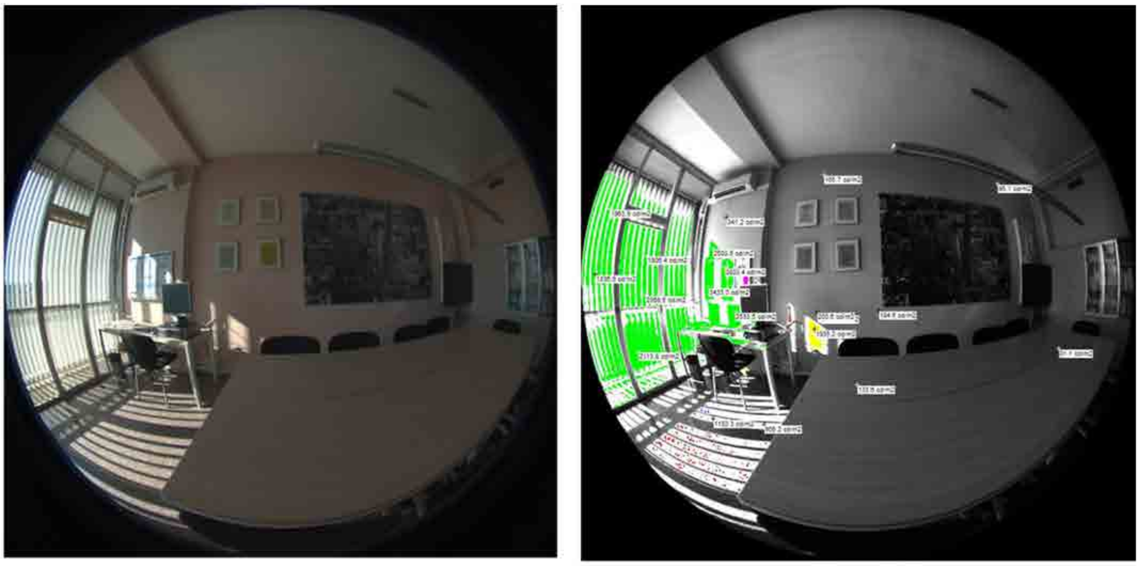


Shading: SLAT-CENTRE	Lighting: OFF	VF 1 (5) 25/09/13 16:40-16:55 (-16,31)	DGI (E) 25 DGP 0,33 Ev 1776 lx Lb 201 cd/m²

figure 5-65: VF 1 (5): data and images of HDR and Evalglare (SLAT-CENTRE)

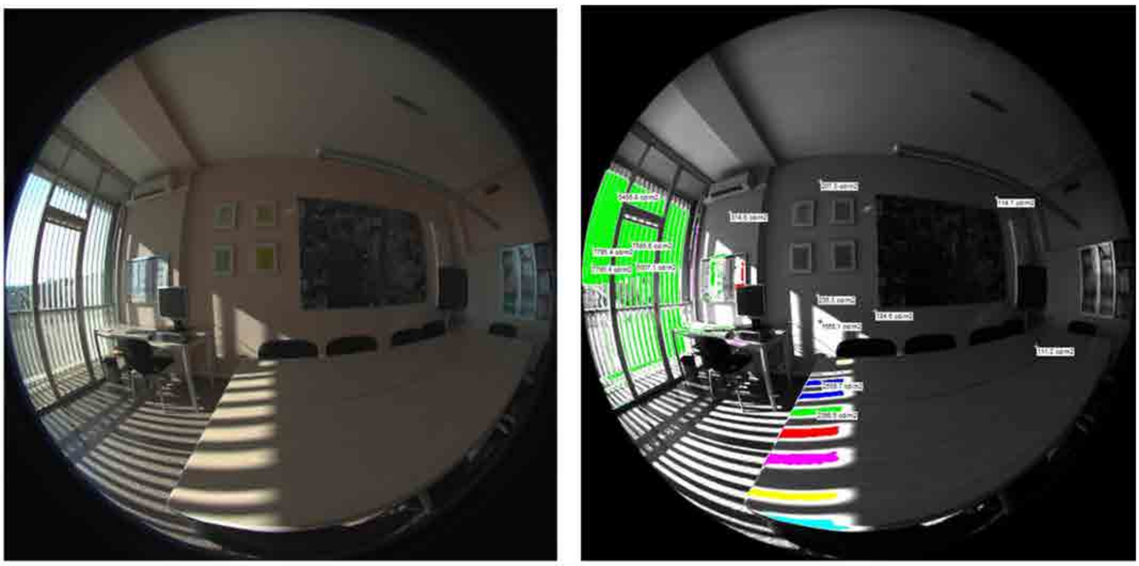
Shading: SLAT-RIGHT	Lighting: OFF	VF 1 (9) 25/09/13 16:55-18:20 (-13,29)	DGI (E) 24 DGP 0,31 Ev 1385 lx Lb 152 cd/m²

figure 5-66: VF 1 (9): data and images of HDR and Evalglare (SLAT-RIGHT)



Shading: SLAT-LEFT	Lighting: OFF	VF 2 (2) 25/09/13 16:30-16:40 (-19,33)	DGI (E) 15 DGP 0,22 Ev 811 lx Lb 179 cd/m^2

figure 5-67: VF 2 (2): data and images of HDR and Evalglare (SLAT-LEFT)



Shading: SLAT-CENTRE	Lighting: OFF	VF 2 (6) 25/09/13 16:40-16:55 (-16,31)	DGI (E) 16 DGP 0,24 Ev 1148 lx Lb 256 cd/m^2

figure 5-68: VF 2 (6): data and images of HDR and Evalglare (SLAT-CENTRE)

Shading: SLAT-RIGHT	Lighting: OFF	VF 2 (10) 25/09/13 16:55-18:20 (-13,29)	DGI (E) 13 DGP 0,21 Ev 566 lx Lb 108 cd/m^2

figure 5-69: VF 2 (10): data and images of HDR and Evalglare (SLAT-RIGHT)

Secondly, the same procedure is repeated around 18:35 pm, when the sunlight and its intensity become lower. The sun's azimuth varies between +4 and +9 and its elevation changes from +14 to +9. This low elevation justifies a variation when the slats are turned to the right. The rotation goes further than 45º. On the graphs (figure 5-70), this position is named "slat right close".

Figure 5-70 presents the graphs with the results corresponding to the different hours and positions of the slats. The DGI results only identify the risk of discomfort glare in relation to the first visual (VF1). No matter the position of the salts, four results surround 24 (disturbing glare) and, even in two situations, the result approximates 31 (intolerable glare). They correspond to the last instants of the sunset (18:20 and 18:50 pm), when slats position is turned to the left and in perpendicular to the façade. In both cases, the sunbeams reach the camera's position and increase substantially the illuminance on the lens, which approximates 3000 lux (last graph). Considering the DGP results, these are the only two situations in which the risk of discomfort glare exists: DGP=0.41 (disturbing) and DGP=0.45 (intolerable).

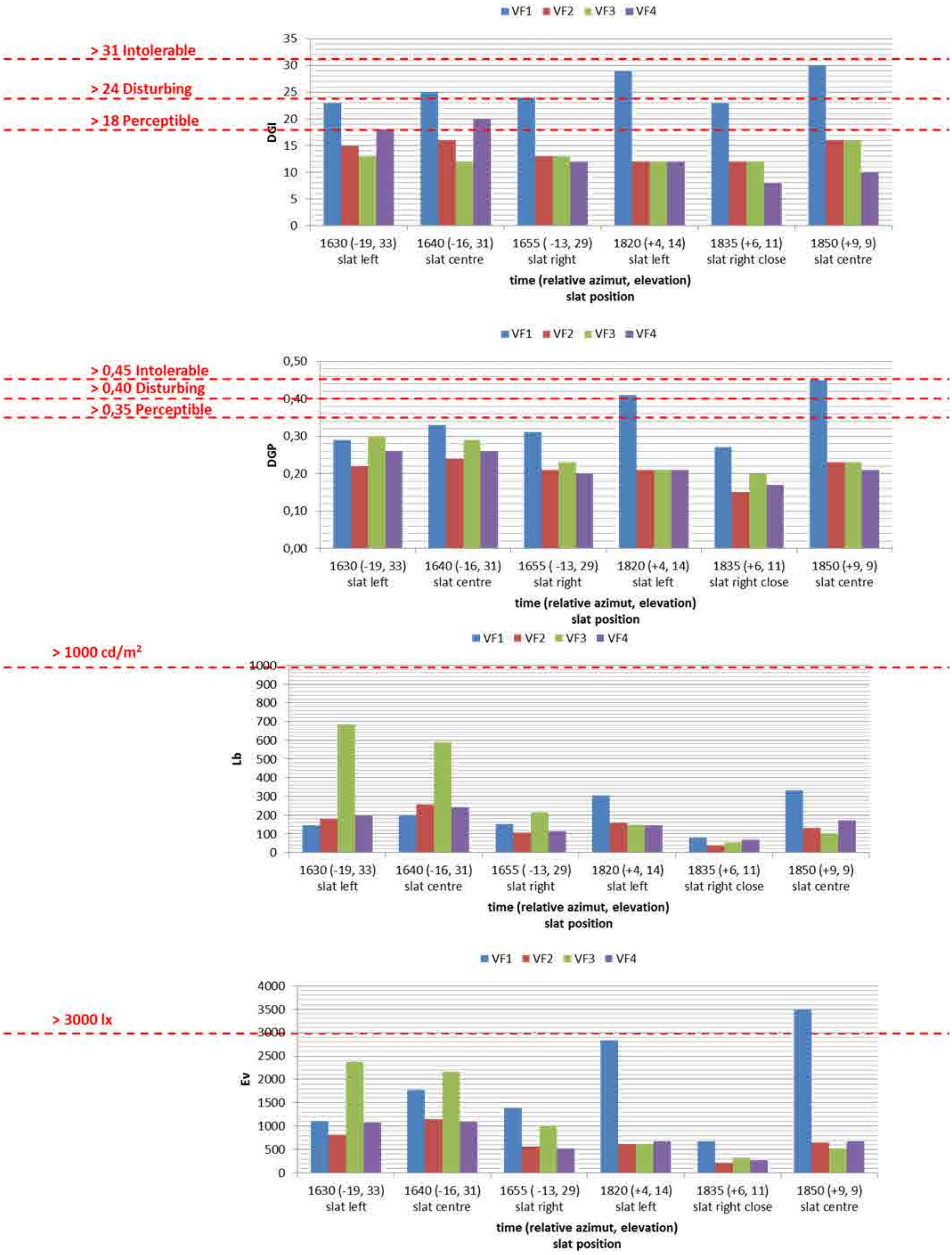


figure 5-70: Results room CiS: DGI, DGP, Lb and Ev of the four VF, comparing different positions of the vertical slats (left, centre and right)

The two next visual fields (VF2 and VF3) correspond to two positions in parallel to the window, which face the same lateral wall but according to different distances from the wall and window. None of the two corresponding glare indexes displays a risk of glare. The DGI results are under 16 and the DGP results are under 0.30, both far from the thresholds of a perceptible glare. Equally, the situation of the last visual field (VF4) is not alarming. The DGI index only uncovers two results close to 18 (perceptible glare), around 16:40 pm, when the slats are turned to the left or in perpendicular. These two positions of the slats permit more access of sun and, from VF4, more vision of the sun's halo through the window.

Another interesting remark points the low variations of the results of a single visual field when the slats turn according to the three assessed positions. If we compare the maximum value and the minimum of the DGI index, around 16:40 pm the differences are: 23-25=2 (VF1), 16-13=3 (VF2), 13-12= 1 (VF3), 20-12=8 (VF4). Around 18:30 pm, the differences are: 30-23=7 (VF1), 16-12=4 (VF2), 16-12=4 (VF3), 12-8=4 (VF4). In general, these differences are not very high. In more detail, these differences are lower around 16:40 than around 18:35 pm, when the sunbeams are more horizontal. Then the position of the slats becomes more relevant. Equally, there are two specific situations in which the position of the slats becomes crucial and provokes high differences. It happens to VF4 at 16:40 pm and VF1 at 18:30. The first case has been analysed in the previous paragraph. The second is due to the position of the slats, turned to the “right close” position which reduces drastically the access of light (Ev very low). The latter leads us to identify a second generality. The highest results are related to the positions with the slats in perpendicular to the façade. In general, this position permits more vision of the sky and more solar access. The opposite happens when the slats rotate to the right. Then, the DGI results register the lowest results.

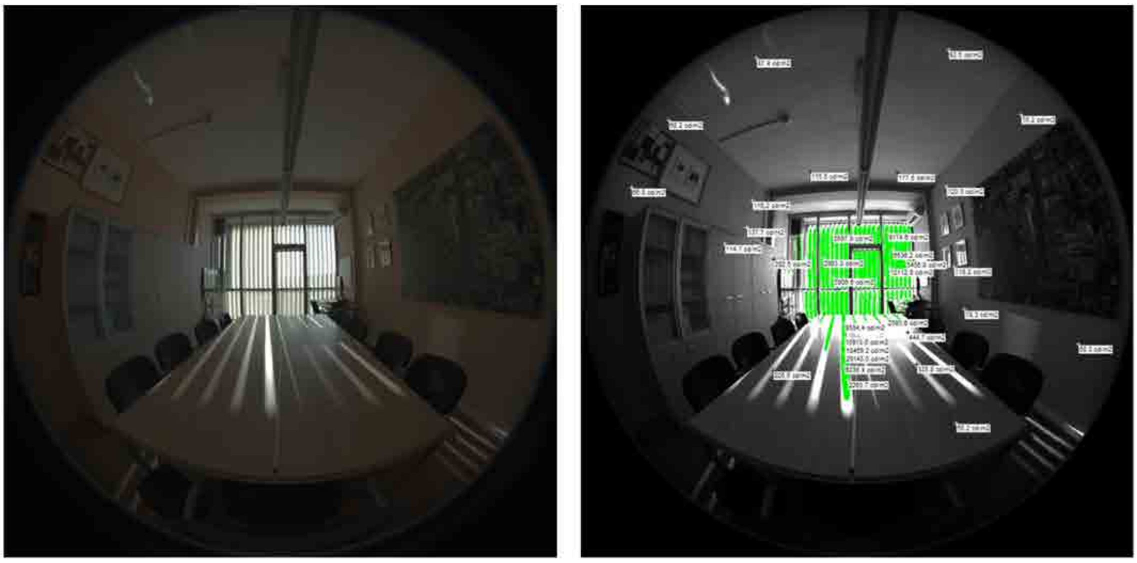
Equally, the DGP results validate the two previous statements. Again, the three different positions of the slats do not cause very high variations if the results of a single visual field are compared. Despite the exception of the first visual field around 18:35 (difference of 0.18), the other situations never surpass a difference of 0.08. In addition, it is also confirmed that the highest risk of glare appears when the position of the slats is in perpendicular to the façade whereas the lowest risk of glare is registered when the slats are turned to the right.

Second variable: alternatives with the vertical slats and the roller screen

The next experiment continues with the same room and the same visual fields (figure 5-63). The purpose is the comparison of two different strategies of shading to face the horizontal sunbeams. The first strategy (figures 5-71 and 5-73) uses the vertical slats when they rotate to the right. This option was identified by the previous experiment as the option with the best performance. Instead, the second strategy (figures 5-72 and 5-74) combines the worst position of the vertical slats (in perpendicular to the façade) with the interior roller screen superposed. The glare calculations will be used to identify which of the two strategies is more convenient to reduce glare.

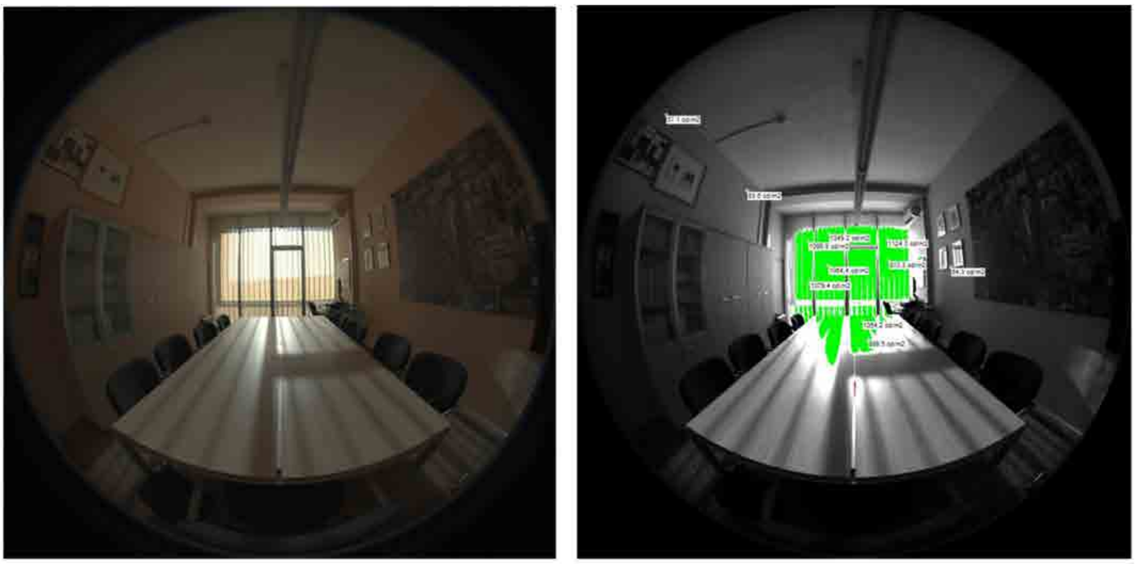
The present experiment took place the 26th of September, one day after the previous experiment. It studies the same four visual fields and the glare repercussions in an equivalent range of hours. Specifically, it compares four sequences of measurements and combines the two strategies of shading. The first sequence starts at 17:30 pm and proposes the first strategy. Then, the second sequence starts at 17:51 pm and uses the second strategy. Again, the second strategy is repeated at 18:21. Finally, the experiment ends with the last sequence at 18:40, using again the first strategy. Approximately the four sequences are separated by time slots of 20 or 30 min. Then, the sun's elevation declines progressively four or five degrees after each sequence. The succession of elevations is as follows: 23, 19, 14 and 10 degrees. Meanwhile, the azimuth varies according to four positions whose angles are symmetrical in relation to the perpendicular of the façade (-6, -2, +3, +6).

Once again, the results of the glare indexes (figure 5-75) display a clear difference between the visual field which faces the window in perpendicular (VF1) and those describing an observer's position in parallel to the window (VF 2, 3, 4). If the DGI results of the first visual field are considered, there is always risk of glare. Two results describe glare as perceptible: DGI=20 at 17:51 (screen + slats-centre) and DGI=21 at 18:41 (slats-right). The two other results advise of the risk of a disturbing glare: DGI=24 at 17:30 (slats-right) and DGI=26 at 18:21 (screen + slats-centre). Regardless the hour or the shading strategy, the DGI results of the three other visual fields (VF 2, 3, 4) are always under 18, the threshold that identifies glare as perceptible.



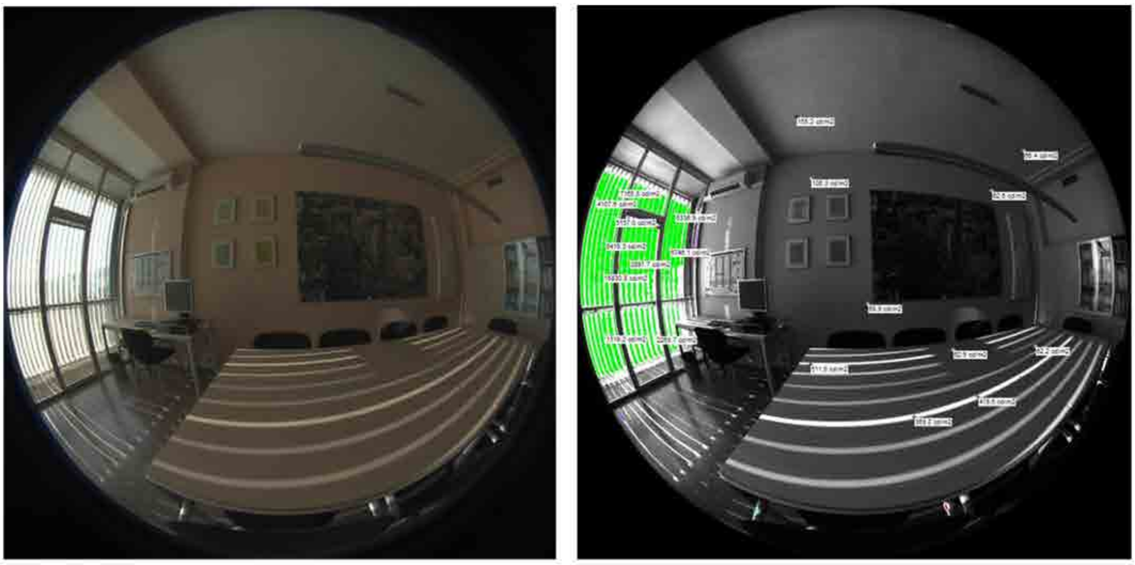
Shading: SLATS	Lighting: OFF	VF 1 (1) 26/09/13 17:30-17:51 (-6,23)	DGI (E) 24 DGP 0,30 Ev 1108 lx Lb 119 cd/m^2

figure 5-71: VF 1 (1): data and images of HDR and Evalglare (screen: WITHOUT)



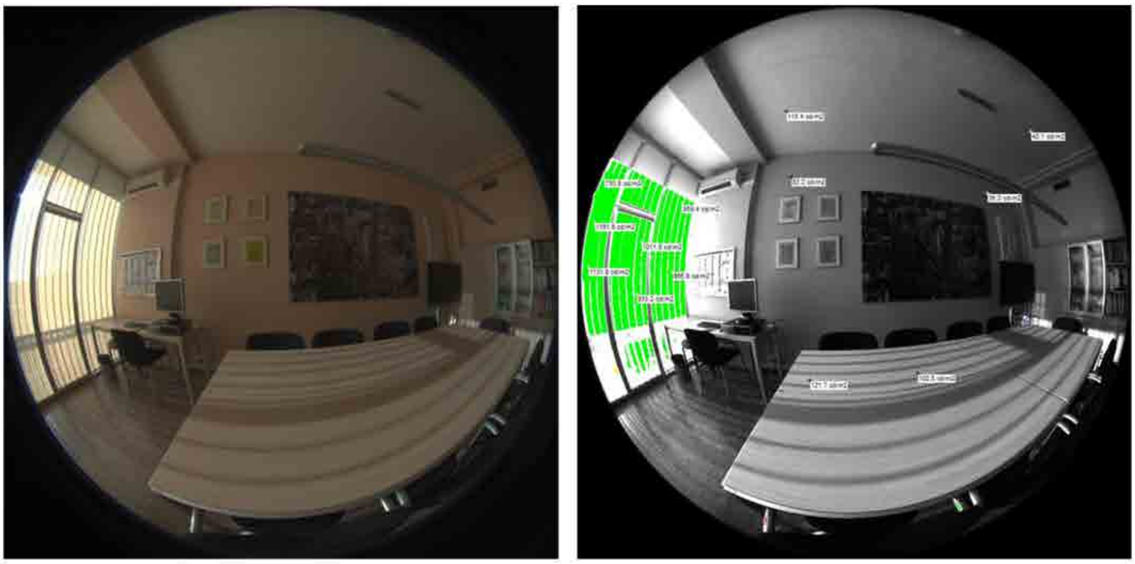
Shading: SLATS + SCREEN	Lighting: OFF	VF 1 (5) 26/09/13 17:51-18:21 (-2,19)	DGI (E) 20 DGP 0,24 Ev 549 lx Lb 77 cd/m^2

figure 5-72: VF 1 (5): data and images of HDR and Evalglare (screen: WITH)



Shading: SLATS	Lighting: OFF	VF 2 (2) 26/09/13 17:30-17:51 (-6,23)	DGI (E) 13 DGP 0,21 Ev 523 lx Lb 99 cd/m²

figure 5-73: VF 2 (2): data and images of HDR and Evalglare (screen: WITHOUT)



Shading: SLATS + SCREEN	Lighting: OFF	VF 2 (6) 26/09/13 17:51-18:21 (-2,19)	DGI (E) 8 DGP 0,18 Ev 297 lx Lb 70 cd/m²

figure 5-74: VF 2 (6): data and images of HDR and Evalglare (screen: WITH)

The DGP results (figure 5-75) interpret differently the risk of glare. All the results are under 0.35 (perceptible glare) and, consequently, they do not judge risk of glare for none of the four visual fields. Nevertheless, the DGP results also identify a clearly different degree of glare between VF1 and VF 2, 3, 4. Considering the four sequences, in general, the difference between VF1 and the other three visual fields varies between 0.07 and 0.14 units.

Previously, the purpose of this experiment has been described as the comparison of two shading strategies. Firstly, the slats are turned to the right and interrupt the view through the window. Secondly, the slats are in perpendicular to the façade and permit the view. In consequence, there is more access of the sunbeams. An interior roller screen is the responsible of the control of the glare effects. In order to determine the repercussions of the two shading strategies, the comparison is more revealing if it pays attention to a pair of sequences under similar sunlight conditions.

The first analysis considers the sequence at 17:30 (slats-right) and the sequence at 17:51 (screen + slats-centre). In both cases, the sunbeams come from the left side of the window (azimuths: -6 and -2). In addition, the sun and its halo are not visible through the window if we consider the most delicate position (VF1) due to the sun's elevation (23 and 19 degrees). Under these sunlight conditions, considering DGI, the differences between the two options are as follows: VF1 (24-20=4), VF2 (13-8=5), VF3 (14-9=5), VF4 (10-8=2). The first value always corresponds to the shading strategy with slats turned to the right. The second value regards the strategy with the roller screen. In consequence, it is possible to affirm that the option with the roller screen always reduce the risk of glare. In general, the results improve 4 or 5 units and, just in one case, 2 units.

The second analysis considers the sequence at 18:21 (screen + slats-centre) and the sequence at 18:41 (slats-right). In both cases, the sunbeams come from the right side of the window (azimuths: +3 and +6). But now, the elevations are lower (+14 and +10) and, unless the shading devices modify the vision, the sun and its halo are visible for VF1, the most delicate position. Under these sunlight conditions, considering DGI, the differences between the two options are as follows: VF1 (21-26=-5), VF2 (11-7=4), VF3 (10-7=3), VF4 (10-7=3) - the second value describes the option with the roller screen.

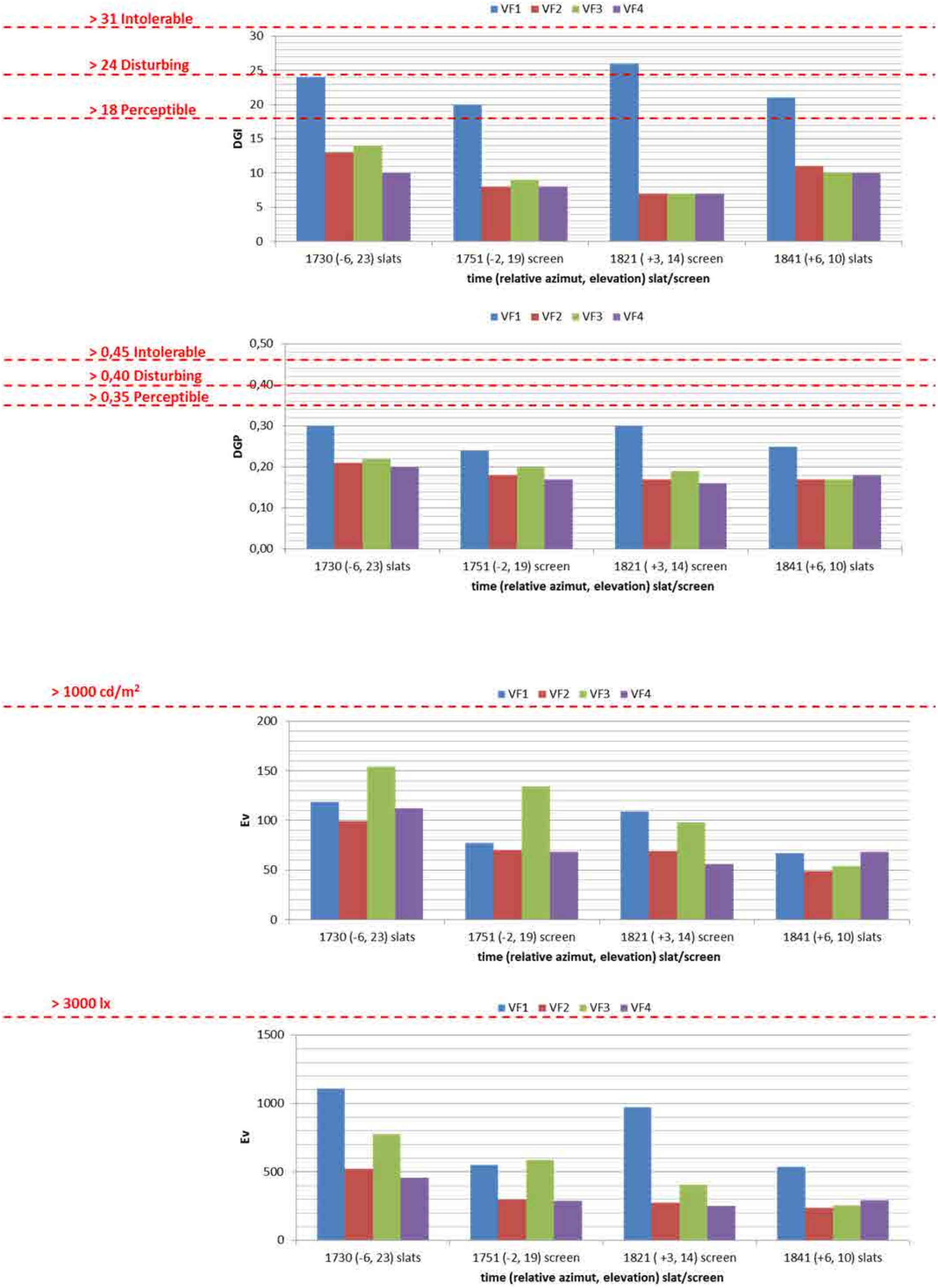


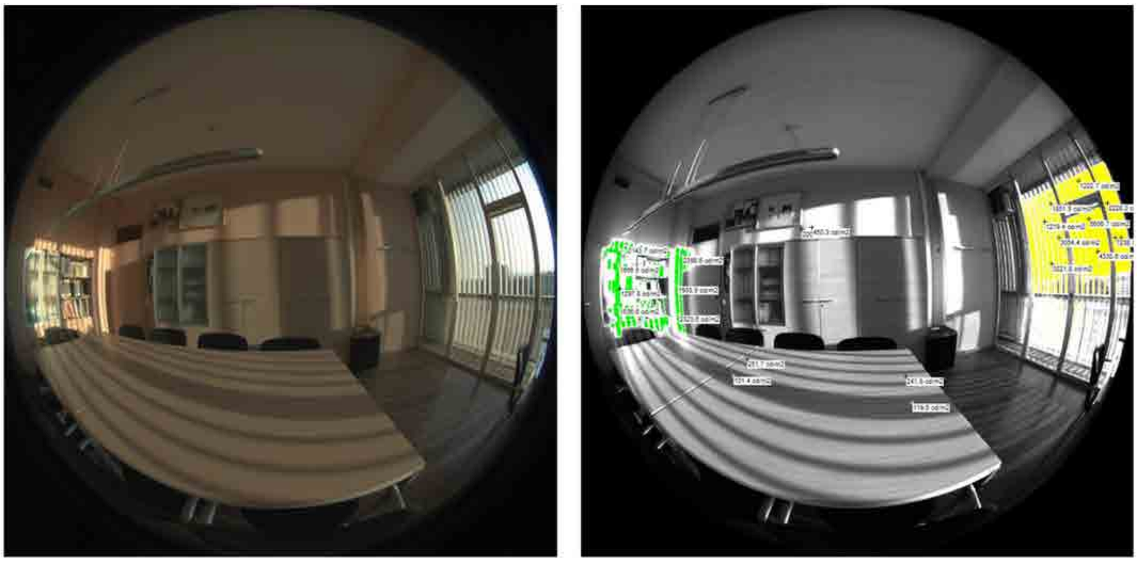
figure 5-75: Results room CiS: DGI, DGP, Lb and Ev of the four VF, comparing two different positions of the screen (with or without)

All the results except one agree with the conclusion of the first analysis. The roller screen reduces the risk of glare and improves the results in 4 or 3 units. The exception corresponds to VF1. With the roller screen, despite the transmission and the diffusion of light, the sun and its halo are still visible with high luminances. Conversely, the option with the slats rotated to the right works better. It hides totally the vision of the sun and its halo whereas the reflections of the sunlight on the white slats are not high enough to cause a high degree of glare.

Overall, the results using the DGP index validate the conclusions exposed previously thanks to the DGI index. The only difference is that there is almost no variation between the results of the visual fields in parallel to the window (2, 3, 4) when the last two sequences are compared.

Third variable: different positions of the roller screen during the sunset

The previous experiment has been useful to validate the favourable contribution of the roller screen in order to reduce the risk of glare. The present experiment studies in more detail this contribution during the critical hours near the sunset, when the sun is still visible through the screen. Thus, the experiment analyses the glare effect in relation to the same four visual fields of the previous experiments thank to four sequences during the last hours until the arrival of the sunset: 18:05, 19:05, 19:16 and 19:35. During all this sequences, the sun is coming from the right in relation to the perpendicular of the façade (relative azimuths: +9, +11, +13 and +16), and its elevation decreases until disappearing in the horizon (elevations: 9, 6, 4 and 0). The experiment combines three different options in relation to the shading devices. The first sequence (figure 5-76) and the last one (figure 5-79) propose the only presence of the vertical slats in perpendicular to the façades. This position of the slats is the one that offers less protection. Then, the second option (figure 5-77) adds the contribution of the interior roller screen. Finally, the third option (figure 5-78) protects only a half of the glazed façade with the roller screen.

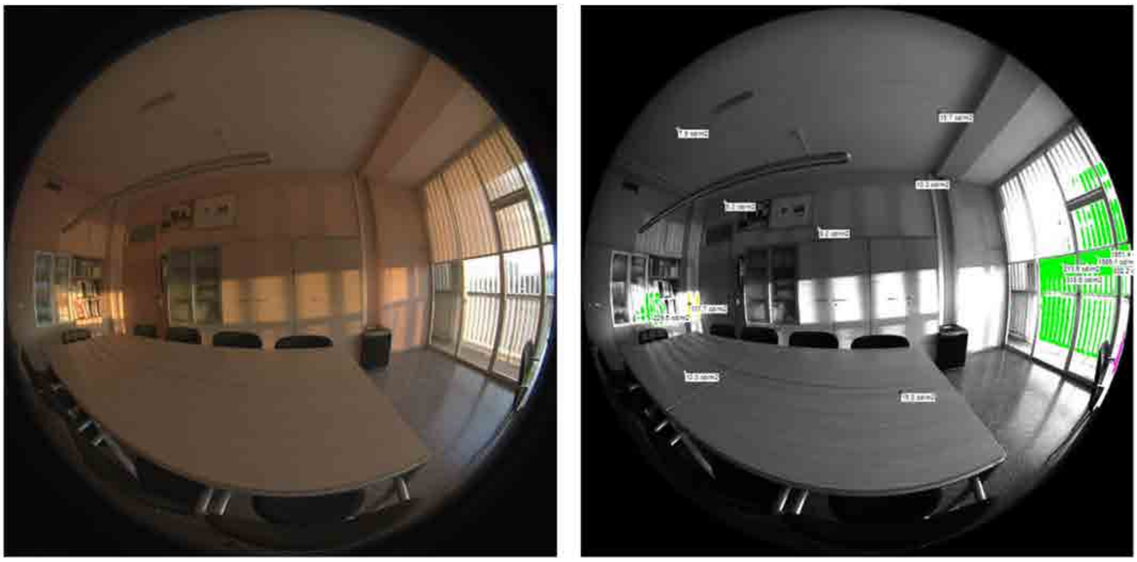


Shading:	Lighting:	VF 4 (24)	DGI (E) 10
SLATS	OFF	25/09/13	DGP 0,21
		18:50-19:05	Ev 628 lx
		(+9,9)	Lb 174 cd/m²

figure 5-76: VF 4 (24): data and images of HDR and Evalglare (screen: WITHOUT)

Shading:	Lighting:	VF 4 (28)	DGI (E) 1
SLATS	OFF	25/09/13	DGP 0,01
+ SCREEN TOTAL		19:05-19:16	Ev 24 lx
		(+11,6)	Lb 6 cd/m²

figure 5-77: VF 4 (28): data and images of HDR and Evalglare (screen: TOTAL)



Shading:	Lighting:	VF 4 (32)	DGI (E) 5
SLATS	OFF	25/09/13	DGP 0,01
+ SCREEN MEDIUM		19:16-19:35	Ev 59 lx
		(+13,4)	Lb 16 cd/m^2

figure 5-78: VF 4 (32): data and images of HDR and Evalglare (screen: MEDIUM)

Shading:	Lighting:	VF 4 (36)	DGI (E) 0
SLATS	OFF	25/09/13	DGP 0,00
		19:35-19:42	Ev 9 lx
		(+16,0)	Lb 2 cd/m^2

figure 5-79: VF 4 (36): data and images of HDR and Evalglare (screen: WITHOUT)

The analysis of the results (figure 5-80) highlights again the particular sensibility to glare of VF1. At 18:50, without the roller screen, the DGI and DGP indexes agree and recognise a risk of intolerable glare. Consecutively, at 19:50 (with screen), 19:26 (half screen) and 19:35 (without screen), the two indexes disagree. Whereas the DGI index equals 18 or 19 (perceptible glare), the DGP results are insignificant. These results are comprehensible after reading the graphs with the extremely low values of Lb and Ev. Considering the three sequences, the highest values of Lb and Ev are, respectively, 18 cd/m2 and 168 lx.

Although they do not surpass the threshold that describes a perceptible glare, the DGI and DGP results are also substantial for VF 2, 3 and 4 during the first sequence, at 18:50 pm, without using the roller screen. The values of Lb and Ev are still remarkable. After that first sequence, the risk of glare is no longer noticeable for VF 2, 3 and 4. Only in one occasion, at 19:16, the DGI result for VF3 identifies a glare as perceptible. The DGP index also reacts, although the result remains under 0.35 (perceptible glare). In that situation, the sun and its halo are visible through the inferior part of the window, which is not protected by the roller screen. Nevertheless, the result is not high because of the low intensity of last sunbeams of the day.

The analysis of the results of the glare indexes corresponding to the two positions of the roller screen requires knowing the particularities of what is perceived by each visual field. The HDR images and the Evalglare representations provide this information. The present document only shows the figures related to VF4 (figure 5-76 to 5-79). For the three other visual fields, the following text will provide a description the details that are relevant to understand the results. Before starting with the analysis, it is also interesting to remember that the DGI results seem to react accurately to the particularities of a wide range of conditions of lighting whereas the DGP results seem less sensitive.

After the previous clarifications, it is possible to start with the first step of the three successive comparisons of the effects of the roller screen, which considers the position of the screen that covers the entire window. All the visual fields register a reduction of minimum 10 units of the DGI index. The reason is a strong reduction of the luminances that are related to the vision through the window and those of the sun patches reflected on the interior surfaces.

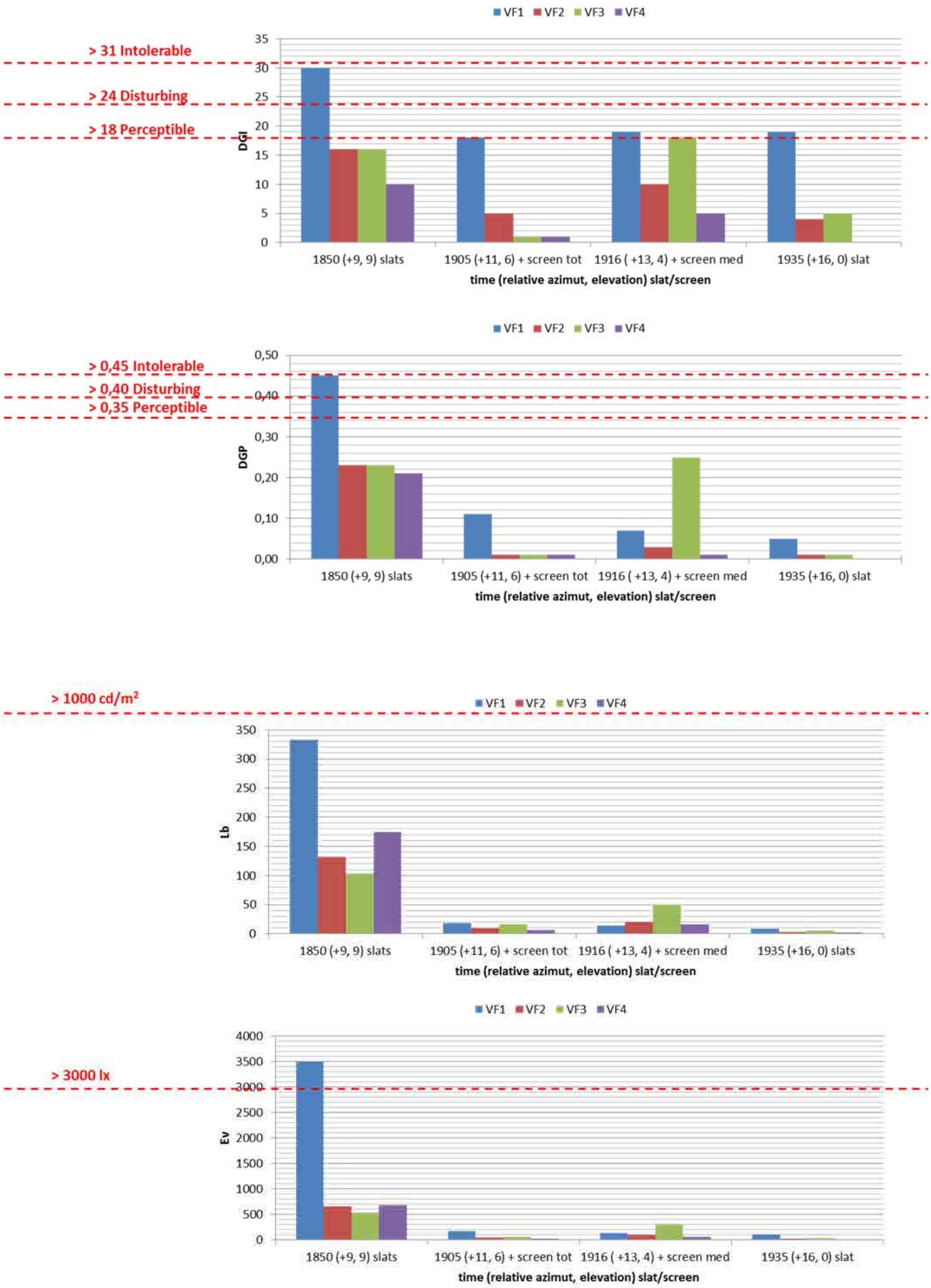


figure 5-80: Results room CiS: DGI, DGP, Lb and Ev of the four VF, comparing three different positions of the screen (without, total, medium)

During next sequence of measurements, the roller screen covers only the superior half of the glazed façade. From the positions of VF 2, 3 and 4, the roller screen does not continue protecting against the vision of the sun and its halo. Consequently, the three results increase considerably if they are compared to the previous position of the screen. Specifically, the result corresponding to VF3 increases extremely (17 units). Within this visual field, the sun and its halo are visible and their position is close to the centre of the vision. Instead, the DGI result related to VF1 only increases one unit. The partial presence of the roller screen is the reason. From the position of VF1, the screen continues covering a notorious part of the sun and its halo.

Finally the roller screen disappears during the last sequence of measurements. In reality the situation does change extremely for VF 2, 3 and 4 because, previously, the sun and its halo were also visible thought the inferior half part of the window (without screen). Despite that, there is a clear reduction of the results of the three visual fields (VF 2, 3 and 4). The reason is the low intensity of the sunbeams at the last moments of the sunset. Instead, the degree of glare of VF1 remains equal. From that position, before, the vision of the sun was obstructed by the screen. Now, without screen, the sunbeams reach the camera again, although their intensity is very low as it has been mentioned previously. The combined effects of these two new circumstances explain the stability of the result of VF1.

5.2.6. Conclusions

The previous experiments consider side-lit meeting rooms. Their façades have big proportions of glazing and face different orientations (south, north and west). The global reading of the results justifies the following conclusions:

- A moderate presence of sun patches in the interior improves the balance of light between the interior and exterior. Consequently, it reduces the risk of glare very often. Under these circumstances, the presence of sunlight in the interiors would be welcomed.

- The risk of discomfort glare is less probable when there are sun patches inside the room, reflected on the surfaces which are near the window, than when they are outside the room, reflected on the bright façades of neighboring buildings.

- Consequently, the risk of discomfort glare due to sunlight is often higher in the north-facing rooms (DGI describes degrees of disturbing glare) than in the south-facing rooms (DGI describes degrees of perceptible glare).

- The effects of artificial lighting (intensity directed to the desks and not to the walls) are insufficient to increase the average luminance of the scene and reduce the risk of discomfort glare caused by the sun patches, no matter if they are reflected inside or outside.

- The horizontal sunbeams which are reflected on the deepest areas of the west-facing rooms increase the risk of discomfort glare. The rapid changes of the elevation and azimuth of the sun are the cause of significant variations in the degree of glare during the afternoon.

- In general the worst DGI results, which are registered in north-facing and west-facing rooms, describe the perception of a disturbing glare. Exceptionally some DGI results reach degrees of intolerable glare in the west-facing rooms.

- In the presence of horizontal sunbeams (west façades), the surfaces of the shading devices increase their brightness; thus, they are often considered as sources of glare, although they do not cause high degrees of glare. The rotation of the vertical slats is not responsible of relevant differences in the degrees of glare. The roller screen appears as the most efficient shading device.

- The position of the visual fields within the room affects significantly the results of the glare indexes (especially when using the DGI index). The visual fields facing the window imply always the highest results. These results are motivated by the position of the glare sources (sky, bright façades, sun patches inside or outside), which occupy the centre of the vision.

- In general, the lateral positions in relation to the window provoke lower degrees of glare because the glare sources (sky and sun patches) do not occupy the centre of the vision. In these cases the proximity to the window and the size of the space become relevant factors. If a big space is analysed, there is always risk of contrast between the darkness of the interior and the lightness of the exterior; thus, the highest glare indexes are registered near window. If a small space is analysed, this contrast of light is only perceived if the hypothetical user occupies a position at the back of the room.

- The DGI index offers the most reliable results in order to judge glare understood as the balance of light conditions, especially affected by the light contrast between the interior and exterior. This index demonstrates a good correspondence with the definition of discomfort glare.

- The DGP index seems to be less sensitive to the balance of light. Its results are clearly subordinated to the values of the vertical illuminance on the lens (Ev). This feature separates the results from the definition of glare understood as the risk of imbalanced light conditions between the sources of glare (Ls) and the background (Lb), corresponding to the definition of discomfort glare. Instead, the DGP index seems valuable to describe glare caused by the presence of a high brightness of the scene, corresponding to the definition of disability glare.

5.3. Side-lit space with “small” windows

5.3.1. Introduction

This last chapter of experimental studies pretends to introduce briefly new relevant aspects that are not considered as the central part of this thesis. They are considered relevant examples of other particularities that can be more extensively assessed in future works. Until now, they were not considered by thesis because they escape to the traditional studies, then they are less comparable. Their links with the previous case studies are recognizable, thus this extension adds comparative remarks and enriches the discussion.

Primarily, three aspects are specific of this chapter. Firstly, the usage of the space is voluntarily undefined. That is why the title of the chapter does not specify the type of room. Figure 5-81 presents graphical information of this room (a plan and an interior façade), which belongs to a building located in Barcelona. Usually, this spacious room combines two usages, dining and living. The chapter pretends to assess the glare effects in ambiguous spaces, without a determined task that implies a specific way of using that space. In order to promote this idea, the existing sofas were removed of the space. Other pieces of furniture remain in the original location. Then, the space combines some pieces of furniture and empty spaces. As a result, there is not a clear identity in the usage of this space. This alternative approach permits more flexibility in the assessments. Unlike other experiments, which assess visual fields in relation to the predicted places where the users are seated, this approach assesses the visual fields in relation to the particularities of the space, its main dimensions and the position of the windows.

The second specific aspect of this chapter regards the orientation of the space (figure 5-81). As the previous aspect, it pretends to introduce complexity in the assessments. The previous chapters studied rigorous orientations (north, south and west). These orientations are commonly assessed by the daylighting research works because their behaviour is clearly different and the results are partly predictable and permit the validation of certain specific hypotheses. The previous chapters study firstly the south orientation which offers sun patches in the interiors in contrast to a backlit urban landscape. Then, they focus the attention in north orientation that implies the presence of the sun patches outside the room, which are reflected on south-facing façades of the neighbouring buildings, in contrast to the general darkness of the room. Finally, the previous chapters introduce the west orientation that implies the prevalence of horizontal sunbeams and the presence of sun patches in the deepest parts of the room. The present chapter considers a southwest orientation that combines all the previous sunlight conditions. According to two different dates close to the equinox (18/09 and 20/09), at different hours (around 12:30 and 17:30 pm), the sun patches appear consecutively inside and outside the room.

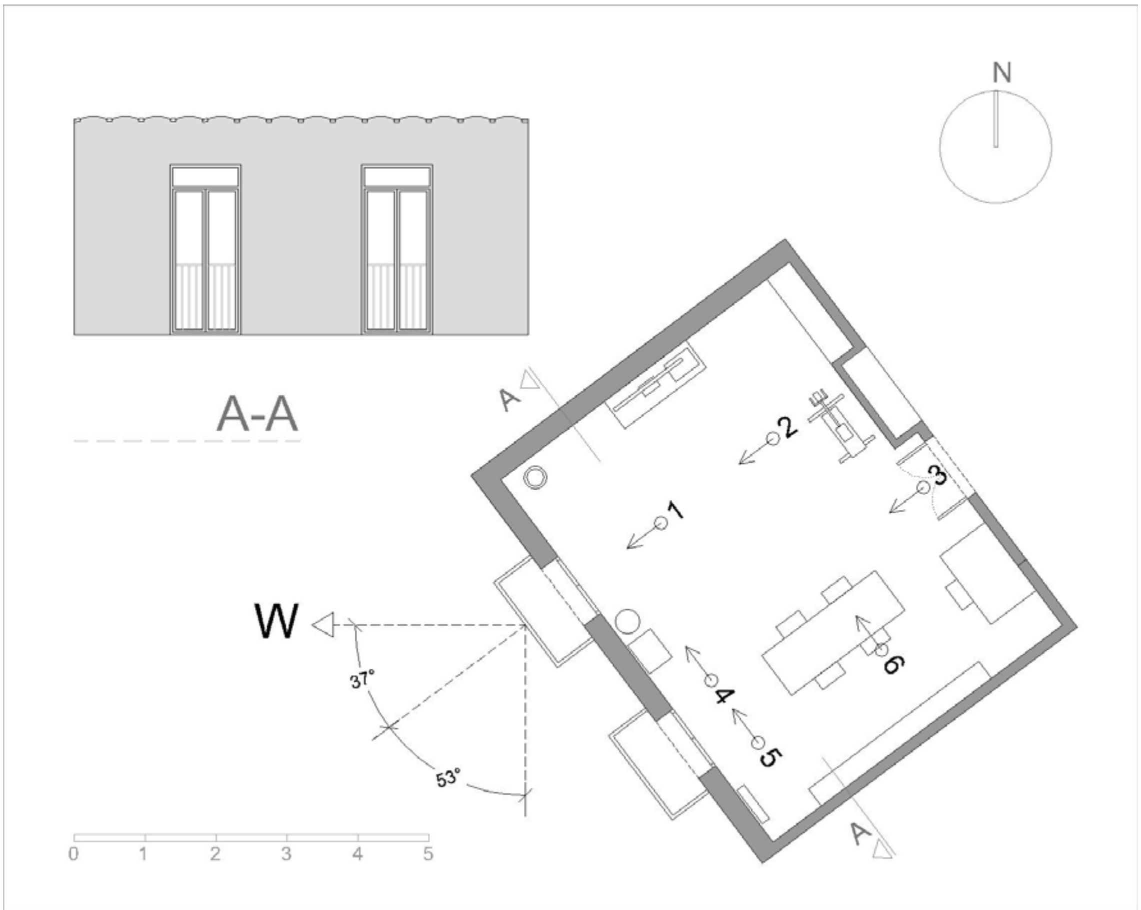


figure 5-81: Room ANGELS and six VF: comparison of the glare effects in a west facing space, considering the position of the sun patches, outside or inside the room

Finally, the third specific aspect of this chapter refers to the proportion of the window in relation to the whole façade. Frequently, the studies assess comfort in small sized rooms with big proportions of glazing in the façades. This circumstance provokes interiors with high levels of light and then a better light balance between the interior and exterior. These are presumably the conditions that correspond with a certain number of office rooms. Nevertheless, in our cities, many buildings that were originally designed as dwellings are now reused as offices because of their privileged location in central areas that imply expensive rents. Therefore, it is reasonable to assess the risk of glare within these spaces where the small windows are more common. The study pretends to be useful to answer the next two key questions that relate the present chapter with the previous ones:

- Considering a façade with “small” windows, is the risk of discomfort glare less probable when the sun patches remain inside the room or when they stay outside?

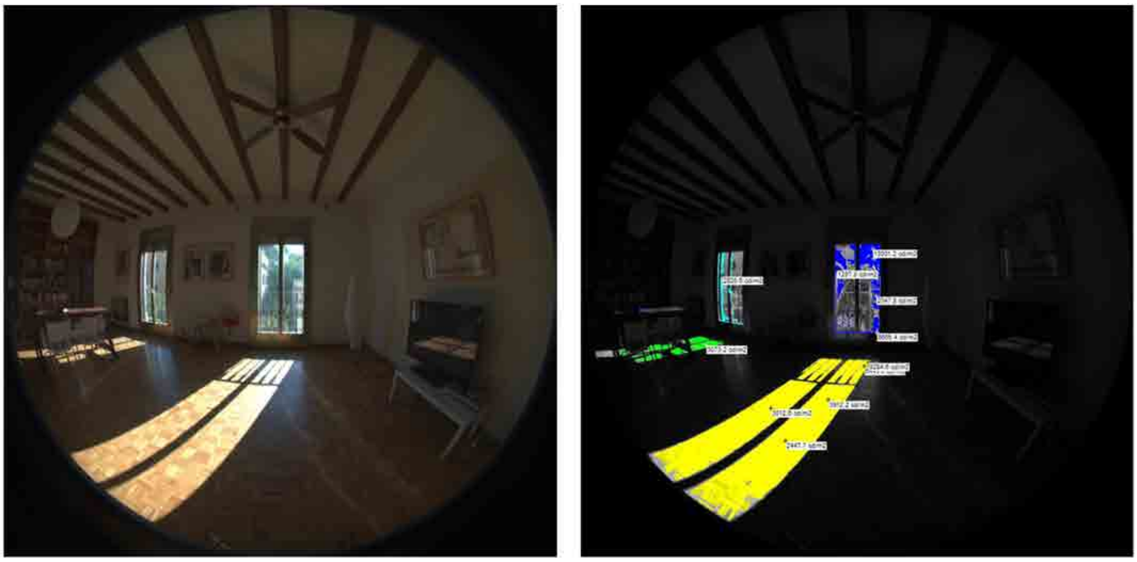
- Consequently, are the façades with “small” windows equivalent to the façades with “large” and “extra-large” windows in terms of risk of discomfort glare due to sunlight?

5.3.2. Sun patches inside and outside the space

Some of the particularities of the space where the current experiment takes place have been mentioned in the introduction. Regarding the windows, it has been said that their proportions are small in relation to the whole façade. Certain specific information can be added now. The figure 5-81 clarifies the position of the windows on the wall and shows their exact proportion. The two windows are vertical glazed doors that facilitate the exit to two independent balconies. Their vertical proportion promotes the solar access into the deepest zones of the space. In relation to the finishes of the surfaces, the next photographs (figures 5-82 to 5-87) give information about the diverse colours of the walls (white), floor (different tones of wood), furniture and decorative elements.

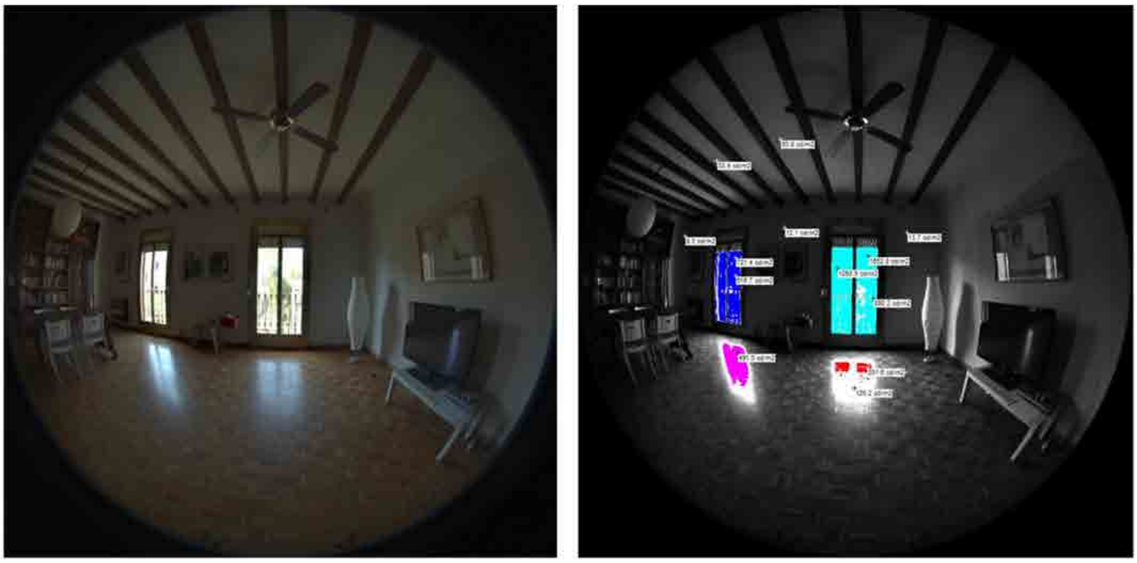
Figure 5-81 positions the visual fields which are assessed. As mentioned before, the choice of these visual fields is not defined in relation to the specificities of a visual task. It pretends to analyse the potential risk of glare in the space. The experiments of the previous chapters were useful in order to identify the most critical positions of the visual fields. In accordance with it, the current experiment defines two sets of three visual fields. The first set (VF 1, 2, 3) studies the views facing the windows. Two views are faced lined up with the right window (VF1 and VF3) and the third view (VF3) is located at the back of the room, on the axis of symmetry between the two windows. The figures 5-82 and 5-83 describe VF2 under two different sunlight conditions. The second set of three visual fields (VF 4, 5, 6) studies the critical positions in parallel to the window. VF4 and VF5 compare two positions near the window: VF4 (figure 5-84 and 5-85) only visualizes one window; VF5 includes the vision of the two windows. Finally, VF6 (figures 5-86 and 5-87) can be compared to VF5 but occupying a deepest position, approximately in the middle of the whole space.

The assessment of the six visual fields was repeated twice. The first sequence of measurements was done the 18th of September, from 17:22 to 17:52, when the sun's elevation was low and there was a clear presence of the sun patches in the interior. The second sequence of measurements was done the 20th of September, from 12:23 to 12:43; during this interval, the sun patches were reflected on the exterior urban landscape (façade and trees) and never entered the interior.



Shading:	Lighting:	VF 2 (2)	DGI (E) 22
NO	OFF	18/09/13	DGP 0,26
		17:22-17:52	Ev 1043 lx
		(+14,25)	Lb 125 cd/m^2

figure 5-82: VF 2 (2): data and images of HDR and Evalglare (sun patches: IN)



Shading:	Lighting:	VF 2 (2)	DGI (E) 20
NO	OFF	20/09/13	DGP 0,13
		12:23-12:43	Ev 172 lx
		(-80,45)	Lb 20 cd/m^2

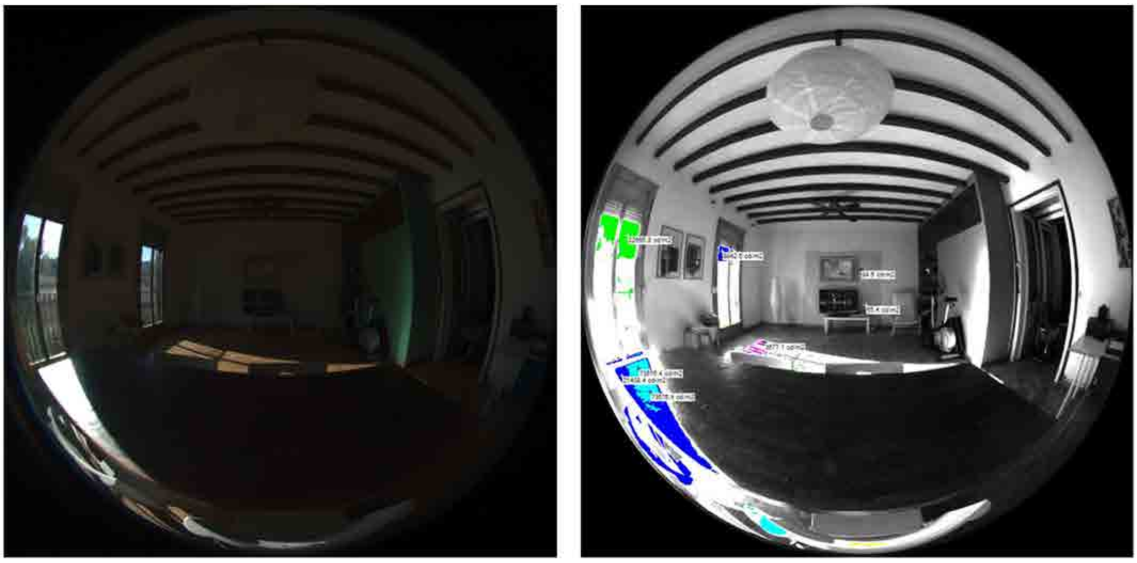
figure 5-83: VF 2 (2): data and images of HDR and Evalglare (sun patches: OUT)

Shading: NO	Lighting: OFF	VF 4 (4) 18/09/13 17:22-17:52 (+14,25)	DGI (E) 17 DGP 0,21 Ev 354 lx Lb 62 cd/m^2

figure 5-84: VF 4 (4): data and images of HDR and Evalglare (sun patches: IN)

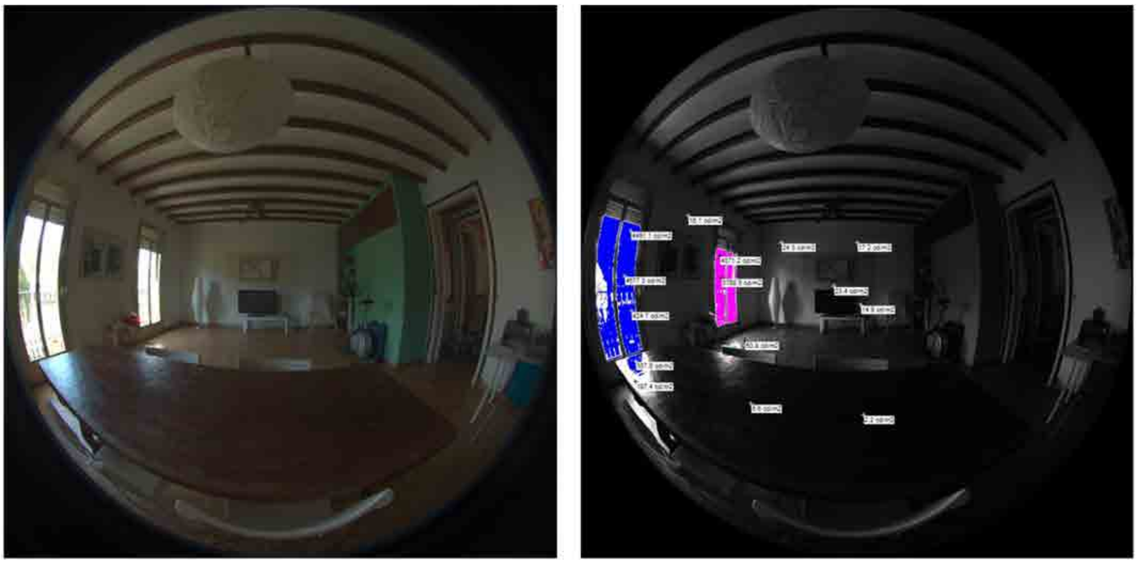
Shading: NO	Lighting: OFF	VF 4 (4) 20/09/13 12:23-12:43 (-80,45)	DGI (E) 19 DGP 0,06 Ev 114 lx Lb 17 cd/m^2

figure 5-85: VF 4 (4): data and images of HDR and Evalglare (sun patches: OUT)



Shading: NO	Lighting: OFF	VF 6 (6) 18/09/13 17:22-17:52 (+14,25)	DGI (E) 26 DGP 0,35 Ev 928 lx Lb 104 cd/m^2

figure 5-86: VF 6 (6): data and images of HDR and Evalglare (sun patches: IN)



Shading: NO	Lighting: OFF	VF 6 (6) 20/09/13 12:23-12:43 (-80,45)	DGI (E) 19 DGP 0,08 Ev 138 lx Lb 13 cd/m^2

figure 5-87: VF 6 (6): data and images of HDR and Evalglare (sun patches: OUT)

Figure 5-88 presents the results of the two sequences of measurements. The light grey vertical bars describe the scene when the sun patches are reflected inside the room. The dark grey bars correspond to the exterior presence of the sun patches. On the top, the graphs related to the values of Lb (left) and Ev (right) clarify that the lighting scenes are clearly different. Both values are clearly low when the sun patches are outside de room.

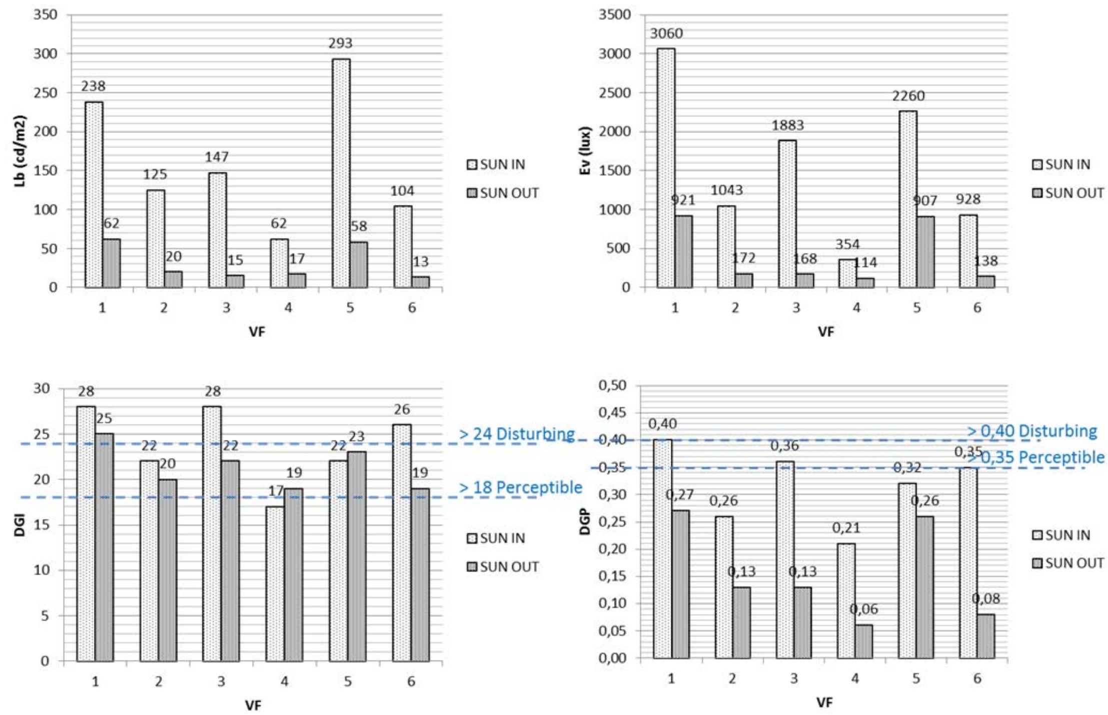


figure 5-88: Results room ANGELS: Lb, Ev, DGI and DGP of the six VF, comparing the position of the sun patches (in or out)

According to the DGI results, glare is always perceptible for the six visual fields, no matter if the sun patches are inside or outside. It can be seen that the highest DGI results are related to the presence of the sun patches in the interior (VF 1, 3 and 6); they surpass the threshold that describes glare as disturbing. Nevertheless, it is not possible to affirm that the presence of the sun patches always increases the DGI results. It does not happen for VF4 and VF5 (sideways and close to the window). The results decrease one or two units when the sun patches are inside. Lb increases in both cases and is responsible of the reduction. For VF4, Lb increases slightly while Ev does not increase as much (figures 5-84 and 5-85). For VF5, both values increase extremely (sun's halo visible within the visual field). Instead, when the DGP index is considered, the risk of glare is always higher when the sun patches are inside the room. Probably, this simplified answer is due to the excessive sensibility of DGP to the value of Ev.

5.3.3. Conclusion

The current chapter starts its introduction with two key questions that focus on the particularities of the glare caused by sunlight when the façades have “small” windows. Thanks to these questions, this chapter is linked with the previous ones. The answers to these two questions are the conclusions of this chapter:

- The risk of discomfort glare due to sunlight seems to be higher when the façades have “small" windows, no matter if the sun patches are inside or outside. The highest results of the glare indexes (DGI and DGP) correspond to presence of the sun patches in the interior. Nevertheless, it would not be appropriate to affirm that the risk of glare is always higher when the sun patches are visible inside. For some fields of vision (sideways and close to the window) the reflection of the sun patches in the interior surfaces improves the light balance interior-exterior and reduces de risk of glare.

- Consequently, the façades with “small” windows are not equivalent to the façades with “large” and “extra-large” windows in terms of risk of discomfort glare due to sunlight. Considering that the window and the sun patches are smaller, normally their intensity is not sufficient to increase the lightness (luminance) of the backgrounds. Then, the light of the scene is imbalanced (bright sources in contrast to a dark background) and the risk of glare more probable.

Chapter 6: Conclusion

6.1. Conclusions and remarks

The case studies are helpful to investigate the balance of light in interiors under sunlight conditions using the glare metrics. Analysis is made of the horizontal visual fields to describe the overall lighting ambient of the interior space. If we take the user's criteria into consideration, these visual fields are relevant when he/she decides to modify the lighting conditions using the shading devices or artificial lighting.

- **Corresponding luminance values of sun patches and sky portions**

The systematic treatment of HDR images, which are converted to luminance maps, makes it possible to identify the potential glare sources, their sizes and luminances. It is possible, therefore, to compare the glaring effects caused by the view of the sky and the sun patches (chapter 5-all). In a first stage of analysis, it is correct to state that both (sky portions and sun patches) are susceptible to causing the same glaring effects because their luminance values have the same magnitude. The measurements were recorded in London (south and north facing spaces), in June-July 2013, and Barcelona (west facing spaces), in September 2013. The luminances of the glare sources vary between 2000 cd/m^2 (clear sky) and 60000 cd/m^2 (sun's halo), and very often, the luminances of the sky and the sun patches have the same order of magnitude (ratios of 1:2 or 1:3 between them).

- **No specific sensitivity of users towards sun patches**

Nonetheless, even if the luminances of the sun patches are not substantially higher than the luminances of the portions of sky, are the users specially sensitive when they perceive the sun patches? Apparently, this is not the case. The answers to a questionnaire reject this hypothesis (Chapter 5-1.2). There is a dispersion of their reactions when the sunlight conditions are not extreme, but they do not treat the sun patches specifically. The sun patches are perceived as a part of the overall scene and considered as glaring as the portions of sky. In fact, the information contained in a sun patch or in a portion of clear sky is fairly equivalent (bright coloured surfaces, without specific information). Despite that, some of the users seem to react affected in terms of their background (nationality or common lighting conditions at work). More research should be conducted to demonstrate this fact.

- **Solar access without discomfort glare**

Considering the results of the DGI indexes, the research rejects the design of façades with shading devices, which completely restrict solar access in the interiors (chapter 5-2.2). This demonstrates that the risk of discomfort glare is infrequent during most of the hours of the working day. There is one main reason for this. Usually in urban contexts, the sunbeams accessing the interiors are due to high sun elevations. Thus, they generate sun patches that stay close to the window. These sun patches are mainly located on the floor, frequently far from the centre of the observer's visual field, and thus, are less annoying. In addition, sunbeams are reflected on the patch and they increase the average luminance of the scene, leading to two facts. Firstly, there are fewer pixels in the image, which are considered as part of the glare sources and, secondly, the luminance of the background increases. The formulation of the DGI index indicates that these two facts motivate low levels of DGI, i.e., low levels of glare. Consequently, we could even say that a moderate presence of sun patches in the interior improves the balance of light between the interior and exterior. Under these circumstances, the presence of sunlight in the interiors would be welcomed.

- **Large versus small windows: glare effects**

The effects of the sun patches inside spacious rooms differ, depending on if the façades are designed with small or large windows (Chapter 5-3). The façades with small windows present an increased risk of glare. The effects of the small portions of sky, viewed through the window, and the sun patches, reflected on the interior surfaces, are insufficient to raise the average luminance of the room, which remains significantly dark. Thus, it is accurate to predict high degrees of glare when the brightness of the sun patches is confronted with the darkness of the background. Nowadays, there are fewer offices located in spacious rooms with small windows. Therefore, the research works rarely contemplate this circumstance.

- **Sun patches outside the room: risk of glare**

The research demonstrates that frequently the risk of discomfort glare is notably high when the sun patches are visible outside the room. This situation happens in rooms facing north when the view through the window is a light-coloured façade facing south (Chapter 5-2.3). Mainly affected by the colour of the inner surfaces, the average luminance of the observer's visual field is low in comparison to the high brightness of the glare sources (portions of blue sky and sunlight, reflected on the façades of the neighbouring buildings). The visual fields facing the windows (the most critical positions) register DGI results predicting the perception of a disturbing glare. Very often the designs of north-facing façades do not consider this relevant problem.

- **Glare caused by horizontal sunbeams**

Another critical scenario occurs when the sun’s elevation is low and the horizontal sunbeams are reflected on the deepest areas of the rooms. This primarily affects the west-facing rooms in the experiments (Chapters 5-2.4 and 5-2.5) and is equally predictable for east-facing rooms. In these cases, the solar azimuth is especially relevant. The sun moves rapidly, around the perpendicular of the façade, being responsible for changes in the size and position of the sun patches, the lightness (luminance) of the background and, therefore, in the results of the glare indices. The risk of discomfort from glare is aggravated when the interior surfaces (gloss paint finish or varnished wood) cause specular reflections in the direction of the observer. This occurs, to a reasonable extent, when the sun is in front of the observer and its elevation is rather low. In this case, the sources of glare are, simultaneously, the sun patches and the portions of sky near the sun’s disc (with extremely high luminance levels). These circumstances imply the highest results of the glare indices (degrees of intolerable glare).

- **Shading devices to minimize glare in east and west-facing rooms**

The rapid movement of the sun in critical positions increases the difficulties when designing shading devices for the east and west façades (Chapters 5-2.4 and 5-2.5). A partially closed roller shutter unduly reduces the amount of light entering the room and accentuates the glaring contrast with the sun patches inside and with the scene outside. Vertical white slats cannot properly control the sunlight when the position of the sun is nearly normal (perpendicular) to the façade. Because of the reflection of the sun's rays, the slats are so bright as to become sources of glare in themselves. Different angles of rotation of the slats do not guarantee improvements in the degree of glare. A roller screen with a suitable fabric, which diffuses the sunlight and gives an internal surface that does not appear excessively bright (with a transmission factor of about 40%), seems to be the most simple and useful shading device: it does not require a constant adaptation of its position, allows for a certain view through it and reduces the results of the DGI index considerably (at least 4 units for the case study).

- **Use of artificial lighting to rebalance an excessive contrast**

This research demonstrates that the effects of the artificial lighting designs analysed are insufficient to increase the average luminance of a scene lit by the sun and reduce the risk of glare caused by the sun patches, whether they are reflected inside (south-facing room, Chapter 5-2.2) or outside (north-facing room, Chapter 5-2.3). The artificial lighting devices that direct the light mainly to the horizontal work plane might be the reason since they do not increase the luminance of the walls (for the observer, the main background).

- **User's position, visual direction and the resulting risk of glare**

The user's position and the visual direction are clearly responsible for the resulting risk of glare. The detailed analysis needs to distinguish between two types of glare. The first type corresponds to a harsh contrast between the brightness of the glare sources (bright sky and sun patches) and the darkness of the interior surfaces (background).

This corresponds to what is defined as discomfort glare. The second type of glare is caused by an excessively high brightness (vision of the sun's disc, sun’s rays reflected on polished surfaces) that saturates the visual mechanism. This is defined as disability glare and has nothing to do with contrast.

In relation to the first type of glare (discomfort glare), the worst positions are those at the back of the room and looking straight through the window. The visual field simultaneously perceives the darkness at the back of the room and the brightness of the glare sources, which are near the centre of vision. These circumstances lead to the highest DGI results in the north-facing room, when the sun patches stay outside and the interior is especially dark. They register degrees of 26 that describe a 'disturbing glare'. Conversely, the lateral positions in relation to the window are responsible for lower degrees of discomfort glare - normally around 18, which is the threshold of a 'perceptible glare' - because the glare sources (sky and sun patches) do not occupy the centre of the vision. In these cases, the proximity to the window and the size of the space provoke differences in the DGI results. If a large space is analysed, there is always the risk of contrast between the darkness of the interior and the lightness of the exterior; thus, the highest results are registered near the sources of glare (window and sun patches). If a small space is analysed, this contrast of light is only perceived if the user occupies a position at the back of the room, where some darkness exists.

The second type of glare (disability glare) occurs near sunset and sunrise, when the sun’s elevation is low, the sun’s disc and its halo are visible through the window, and the horizontal sunbeams are reflected on the deepest areas of the rooms. This primarily affects the east- and west-facing rooms (Chapters 5.2.4 and 5.2.5) and, occasionally, the north-facing rooms in summer (5.1.3). Once again, inside the space, the positions facing the window directly and the sunbeams register the highest DGI results. The results reach degrees of glare of 31 (intolerable glare), the highest of all the experiments. The lateral positions in relation to the window can also be affected by the direct and reflected sun rays if the user is sitting near the window: degrees of glare of 25 (disturbing glare) are registered during the experiments in the north façade of the multi-side lit room (chapter 5.1.3) and in the west façade (Chapters 5.2.4 and 5.2.5).

- **Reliability of the DGI and DGP metrics to assess discomfort and disability glare under sunlight conditions**

When the research studies set out to test the reliability of the glare metrics, it is appropriate to insist on distinguishing between the three types of glare (discomfort glare, disability glare, and veiling reflections). This research does not discuss the annoying effects of sun patches on a computer screen, which might disturb a visual task related to office work. This situation is related to the veiling reflection studies. Nevertheless, the metrics and the techniques to measure discomfort and disability glare (specifically DGI and DGP) are one of the main subjects of the research.

The DGI index offers the most reliable results for judging glare understood as the balance of light conditions, especially affected by light contrast between the interior and exterior. This index demonstrates a good correspondence with the definition of discomfort glare. Equally, it reacts properly when extremely bright sources are visible within the visual field and warns of an intolerable glare. Thus, this index is also reliable for assessing situations of disability glare.

The DGP index seems to be less sensitive to the balance of light. Its results are clearly subordinated to the values of the vertical illuminance on the lens (Ev). Often, a threshold of the Ev value (3000 lux) appears as an approximate limit between comfort and discomfort. This feature separates the results from the definition of glare understood as the risk of imbalanced light conditions between the sources of glare (Ls) and the background (Lb), corresponding to the definition of discomfort glare. To illustrate this point, in the assessments related to the north-facing room with the presence of sun patches outside, despite the high contrast between the interior and exterior, the DGP results do not warn of a risk of glare from the position at the back of the room (Ev is considered too low). Instead, the DGP index seems valuable to describe glare caused by the presence of a high brightness of the scene, corresponding to the definition of disability glare. These remarks related to the reliability of the DGP index seem reasonable since the author of this index (Wienold, 2009a) informs of its response limits when assessing scenes with a low brightness.

Regarding the techniques of measurement under sunlight condition, it is necessary to add a consideration in relation to the limits of accuracy. When using a CCD camera or a normal camera to produce HDR images and luminance maps, the researcher should be aware of the limits of their ranges of measurement: the luminance of the sun and its halo are likely to be underestimated (Chapters 5-1.3, 5-2.4, 5-2.5 and 5-3.2).

Considering the most extreme situations, some questions are suggested in order to add arguments for discussion regarding the reliability of the glare indices. Should we consider alternative metrics when assessing the vision of the sun or its reflection on specular surfaces? If we consider the vision of small bright patches, should we test the reliability of other formulations more commonly used for the small and artificial glare sources (BRS, CGI and UGR)? And finally, is it correct to assess discomfort glare and disability glare with the same metrics? Further research is needed to answer these questions.

6.2. Future Outlook

The previous chapter is useful in describing the conclusions and anticipating the convenience of further research that could validate these conclusions more firmly. This chapter enlarges on some of these issues and puts them in relation to other research works that also point to the need for more investigation in the same direction.

The literature review refers to the valuable contribution of the research project entitled *Sunlight in Buildings* (Hopkinson & Watson, 1973/74; Ne’eman, Craddock, & Hopkinson, 1976; Ne’eman, Light, & Hopkinson, 1976). This work incorporates the results of a massive survey that serves as a reference to establish links between the requirement of sunlight, architectural usages and visual tasks. All the interviews were conducted in London and the authors advised that it was appropriate to extend this kind of assessment to other places with different climates. As occurs with thermal aspects, lighting preferences may also be subject to different sensitivities, depending on individual adaptation capacity. To date, further work is still needed to define the lighting preferences in relation to the local culture.

The first case study of this thesis proposes the assessment of glare by means of a calculation methodology that is complemented by a survey. The same lighting situation in the presence of sunlight is judged by subjects of different nationalities. The questionnaire asks them about the annoyance caused by the presence of sun patches during the experiment. The reading of the results leads us to conjecture that their sensitivity could be linked with a certain cultural bias. Equally, the interviews made it possible to note the lighting conditions in which the respondents usually work. The fact of being used or not to the presence of sunlight in their everyday environment can also determine their appraisal. However, the number of respondents is not as high as to warrant an unequivocal judgment. The procedure followed in this survey could be repeated in future works including a greater number of respondents.

The same survey proposes the comparison of the glaring effects of the windows and sun patches. The information content of these two surfaces reveals the proximity of the outdoor natural environment. Users appreciate this vision and demonstrate a greater tolerance towards the glare effects that they could cause. Tuaycharoen and Tregenza (2005, 2007) focus the attention on the case of windows. Boubekri and Boyer (1992) deal with the comparison and suggest that the degree of tolerance is greater in the presence of sun patches. The questions in the survey of this thesis interrogate the users. They distinguish between the effects of these two glare sources and link them with the vision of the whole scene. However, the results are insufficient to validate categorical conclusions. The working methodology does not appear to be the problem. Once again, a greater number of respondents and lighting scenes would seem necessary.

The contribution of further work using surveys could also be helpful to add new knowledge regarding the reliability of the glare indices. The experience of this thesis compares the results obtained by means of two indexes: DGI and DGP. The authors of the DGP index (Wienold & Christoffersen, 2006) indicate that its formulation requires more effort to be validated in situations with moderate light levels. The mathematical expression lends considerable importance to the total vertical illuminance at the observer’s position. Giving great weight to this parameter, the results indicate whether a scene causes glare. Apparently, the index correctly estimates the risk of glare caused by an excessive amount of light but it is less effective when it considers the trouble that provokes the excessive contrast between the high luminance of the glaring surfaces and the lower luminance of the background. The DGI index is based solely on the logarithmic comparison of these two parameters (similar to the characteristics of the perception of human senses). Its results seem to be more accurate when judging the light balance of indoor spaces. Further research is needed to validate this statement.

Finally, the thesis restricts the field of study to the glare effects that cause the solar presence without simultaneously considering other aspects. It provides the necessary information to be aware of the design consequences implied by glare control. However, this information is only a fraction of what is required to design certain architectural elements, e.g., shading devices. The thermal effects are equally influential and should be analysed simultaneously in future works. The joint work of Reinhart and Wienold (2011) points in this direction and is definitely a recommended reference.

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List of figures

List of tables

List of equations

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List of symbols

BGI	British Glare Index
CGI	CIE Glare Index
DGI	Daylight Glare Index
DGI_N	New Daylight Glare Index
DGP_S	Simplified Daylight Glare Probability
DGP	Daylight Glare Probability
DGR	Daylight Glare Rating
E_d	Direct vertical illuminance at eye due to all sources [lux]
E_i	Indirect vertical illuminance at eye [lux]
E_v	Vertical illuminance at eye level [lux]
F_v	Average luminance for the entire field of view [cd/m²]
G	Glare constant
L_b	Background luminance [cd/m²]
L_c	Average luminance of the ceiling [cd/m²]
L_{ext}	average vertical unshielded luminance of the outdoors [cd/m²]
L_f	Average luminance of the floor [cd/m²]
L_w	Average luminance of the walls [cd/m²]
L_{window}	Average vertical shielded luminance of the window
L_{adapt}	Average vertical unshielded luminance of the surroundings
L_s	Glare source luminance [cd/m²]
L_{wp}	Luminance visible within the window plane
M	Index of sensation for glare source
n	Number of glare sources
P	Guth's position index
PGSV	Predicted glare sensation vote
UGR	Unified Glare Rating system
VCP	Visual Comfort Probability [%]

Greek letters

P	Position index [-]

Φ_w	Configuration factor for the window
Ψ	Angular displacement of the glare source from the observer's line of sight
ω_c	Solid angle subtended by the ceiling [sr]
ω_f	Solid angle subtended by the floor [sr]
Ω_N	Solid angle subtended by the glare source (window) to the point of observation [sr]
ω_s	Solid angle subtended by the source [sr]
Ω_w	Solid angle subtended by the walls [sr]
Ω_s	Solid angle subtended by the source, modified by the position of the source [sr]
Ω_{pN}	Position factor depending on the geometry of the window and the distance from the observation place to the centre of the window area

APPENDIX A

QUESTIONNAIRE FOR THE USER ASSESSMENTS

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Name:	Surname:	Office:
Number:	Hour:	Date:

1. Gender:	
Female	Male

2. When doing office work, do you wear glasses or contact lenses:		
Yes, glasses	Yes, contact lenses	No

3. In case of wearing them, is it for:	
Reading	Long sight

4. Age:				
Under 25	25-35	36-45	46-55	Over 55

5. Do you consider yourself as sensitive to light:				
Much lower than normal	Slightly lower than normal	Normal	Slightly higher than normal	Much higher than normal

ASSESSMENT RELATED TO A PARTICULAR MOMENT WITH SPECIAL DAYLIGHTING CONDITIONS (SUN PATCHES INSIDE THE ROOM)

Please, read the proposed text on your screen during 1 minute. Sometimes, relax your vision with some views of your surroundings (inside space and view through the window). Then, answer the next questionnaire.

6. Do you consider the sun patches were:						
Very Annoying	Annoying	Slightly Annoying	Neither Annoying or Pleasurable	Slightly Pleasurable	Pleasurable	Very Pleasurable

7. Please, describe the difficulty of working while the sun patches are in the space				
Very Difficult	Difficult	Neither Difficult or Easy	Easy	Very Easy
8. The degree of glare you experienced from the sun patches was:				
Just Intolerable	Just uncomfortable	Borderline between Comfort and Discomfort	Just Acceptable	Just (Im)perceptible
9. The degree of glare you experienced from the windows was:				
Just Intolerable	Just Uncomfortable	Borderline between comfort and discomfort	Just Acceptable	Just (Im)perceptible
10. The degree of glare you experienced from the overall scene was:				
Just Intolerable	Just Uncomfortable	Borderline between comfort and discomfort	Just Acceptable	Just (Im)perceptible

Poem on the computer's screen:

Funeral Blues

Stop all the clocks, cut off the telephone,
Prevent the dog from barking with a juicy bone,
Silence the pianos and with muffled drum
Bring out the coffin, let the mourners come.

Let aeroplanes circle moaning overhead
Scribbling on the sky the message 'He is Dead'.
Put crepe bows round the white necks of the public doves,
Let the traffic policemen wear black cotton gloves.

He was my North, my South, my East and West,
My working week and my Sunday rest,
My noon, my midnight, my talk, my song;
I thought that love would last forever: I was wrong.

The stars are not wanted now; put out every one,
Pack up the moon and dismantle the sun,
Pour away the ocean and sweep up the wood;
For nothing now can ever come to any good.

APPENDIX B

PUBLICATIONS LINKED TO THE THESIS

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Atención / Attention

Las páginas 309 a 314 de la tesis el contienen el trabajo presentado en el congreso / Pages 309-314 of the thesis contains the work presented at the

PLEA 2011

Alexis AGUILAR, Carlos ALONSO, Helena COCH, Rafael SERRA. *Solar radiation and architectural design in Barcelona : reconciling protection in summer and gain in winter.* 27th Conference on Passive and Low Energy Architecture, Louvain-la-Neuve, Belgium, 13-15 July 2011, p. 59-64

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LUMINANCES AND VISION RELATED TO DAYLIGHTING

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ABSTRACT

Daylighting has an excellent color rendering, as human eyes have been developed under the sun's rays, and it yields very proactive elements to human behavior.

In the field of luminance contrast, it has been noted that the probability of excessive contrast is lower when considering daylighting in relation to artificial lighting.

As a result, in activities which require more demanding visual accuracy, daylighting can offer more and better conditions for light and space variations considering the wide range of the field of vision.

This paper proposes a new approach to the methodology of calculating luminance balances considering the surface position in space and its relative weight in the final mean luminance value. This is based on ergonomic field of vision distribution, which confers major importance on what is in the solid angle analyzed by the cones area of the eye. The starting point when constructing numerical models of lighting comfort is the human eye's sensitivity to light.

Assessing interior architectural visual comfort conditions is the ultimate purpose of this work, along with the possibility of taking advantage of photography-related software programs that could be useful tools for architects and interior designers.

Avoiding uncomfortable visual situations is an environmentally efficient approach because the end effect of poor visual conditions is a higher demand for artificial lighting, leading to energy consumption that could be saved with lighting conditions adapted to human comfort.

1. INTRODUCTION

Lighting comfort in an inhabitable space depends on the amount of light and how it is distributed. Naturally, users are more demanding when they find themselves in work spaces that require a high visual effort. Projects that aim to create an interior space with bright light yet without thinking about the balance of the light lead to uncomfortable situations, such as glare, for example.

Light sources are the main cause of unsatisfactory luminance balances [1]. For this reason, projects that use artificial lighting are so different to those that are resolved with natural daylight. Artificial lighting is more flexible when the distribution of lamps is planned (isolated light sources or smaller sources with lower intensity). However, daylighting depends on the windows (extensive light sources with high luminance), which always provide lateral light and often yield spaces with imbalanced lighting. The lighting levels tend to be quite high near the windows, and there is the risk of it being quite low in spots far from the windows. Furthermore, when the window appears within the user's field of vision, its high luminance is often the cause of glare.
This risk is particularly noticeable in climates characterized by having clear skies, such as the Mediterranean. The luminance of the sky associated with the window is quite high and proves to be more of a stumbling block to design solutions [2].

But design solutions are not the only problem. The evaluation methodologies themselves must be sensitive to the diversity of possible cases (artificial or daylight, cloudy or sunny skies). The classic formulation associated with glare offers coherent results when it evaluates cases of artificial lighting, but it is more difficult to apply in cases with daylighting, which is especially critical when dealing with very bright skies. In this last scenario, the calculations of glare would reveal that almost any window, regardless of its position with regard to the user, causes glare. However, experience tells us that this is not always so. [3] [4]

The purpose of this article is to provide further details and offer possible alternatives to calculation methods related to the luminance balance. The goal is for these methods to be more suitable to the particularities of daylighting, more specifically when evaluating cases with very luminous skies.

2. METHODOLOGY

The methodology used inspires an explanation with special reference to the particularities of the proposed calculation. Table 1 summarizes the stages in the evaluation process. Below the table, the particular features of each stage are explained in detail with a section for each of them.

TABLE 1: SUMMARY OF THE STAGES IN THE PROCESS

No.	STAGE	DESCRIPTION
1	Measuring instruments	Fisheye photography + Luminance meter
2	Luminance maps	HDR software + Calibration system
3	Image processing	Visual field + Solid angles calculation
4	Average luminance calculation of the visual field	Physiology of the eye + Comparative calculations with different models
5	Luminance balance of the visual field	Proposal for a calculation model

2.1 Measuring instruments

Two measuring instruments were used.
The first is a camera fitted with a circular fisheye lens (Sigma 4.5 mm F2.8). The result of the photographs taken with this lens is circular pictures inside the projection frame. The projection used is hemispheric and is known as the “equisolid angle projection”. Its unique feature is that it retains the proportions among the solid angles. The purpose of the photographs taken with this lens is to simulate the visual field of the human eye. However, vertically, the aperture angles of the lens are greater than those of the eye. As a result, the pictures are processed to eliminate the upper and lower parts from the evaluation, which should not be counted when simulating human vision. [5]
The second instrument is a device to measure luminances (Konica Minolta LS-110). Its acceptance angle is 1/3º and its measurement range is from 0.01 to 999900 cd/m^2. Both limits are enough to verify the measurements taken in this case study, as these margins were not exceeded in any case.

2.2 Luminance maps

By using the WebHDR software created by Axel Jacobs [6], digital photography can become a “map of false colors” which represents the luminances present in a space. This software enables us to choose between a logarithmic or linear scale of representation. The logarithmic scale is used since it more clearly represents the luminances in the case study. The scale offers ten possible luminance values (Fig. 1) which fit a predetermined range between 0 and 1000 cd/m^2. This range is sufficient to represent the luminances existing in an interior space.
Only the luminance from the outdoors, present in the windows with a value higher than 1000 cd/m^2, is outside the range. The software represents their value by associating them with the maximum value on the scale. In these cases, the value is replaced by the one provided by the luminance measuring tool.

Furthermore, a second reason justifies correcting the luminance of the windows. The WebHDR software graphically uses red and blue to warn that certain areas do not offer reliable luminance values, such as the areas that represent the luminance of the windows. When overexposed to light, their luminance value must be reconsidered. The luminance measuring tool solves this problem by providing the precise value, plus it also serves to calibrate the WebHDR software.

In parallel, and specifically for this study, the authors of this article developed their own software to read the luminosity of each pixel in a picture. The program reads the three RGB coordinates of each pixel, and adds them together to yield a luminosity value for a photograph which can vary between 0 and 765. After that, this luminosity value becomes a luminance value of surfaces through a normalization factor that is defined using the values of the luminance measuring tool. The purpose of this software is to provide a calculation tool that allows for a higher degree of detail.

2.3 Image processing

Image processing enables us to quantify the presence of each luminance within the field of vision. The first geometric operation is to eliminate two portions (an upper and a lower) from the circular image. The angular apertures of human vision define the limits of each portion. The lens used yields images that respect the "equisolid angle" geometric projection, whose main characteristic is that it retains the proportionality among solid angles, so we can directly measure the image. Two surfaces of the same size represent the same solid angle, regardless of their position in the image. Once this property is known, two calculation methods are put into practice.

The first consists of superimposing a template over the image yielded with WebHDR (Fig. 1), which is used to measure the area units of the same size (same solid angle). Each area is then associated with a given luminance and an angular deviation with regard to the centre of vision.

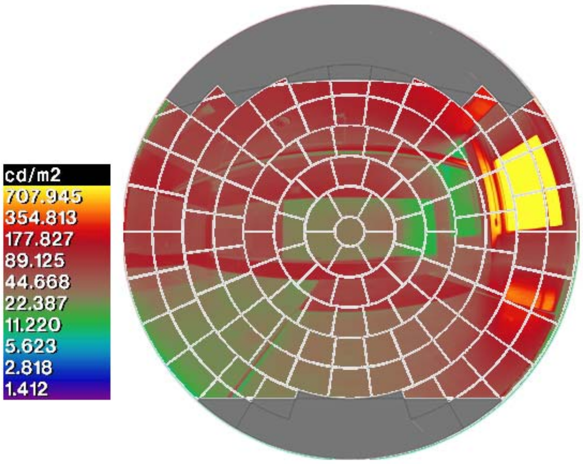

Figure 1: Subdivisions with the same solid angle superimposed on the WebHDR image.

The second method uses an original photograph and the software created by the authors of this article. The software enables the luminosity of each pixel (turned into luminance) to be associated with its position with regard to the centre of vision.

2.4 Average luminance calculation of the field of vision

The calculations of glare offer a comparison between the luminance of a light source and that of a visual background, which can be associated with the average luminance of the field of vision. The average luminance can be calculated using the following mathematical expression: [7]

$$(1) \quad Lmed = \frac{\sum L_i \times \omega_i \times f(\theta)}{\omega_0}$$

Where:

L_i is the luminance associated with a solid angle;
ω_i is the solid angle of each luminance;
ω_0 is the solid angle of the field of vision; and
$f(\theta)$ is the function that weighs the luminance by lowering its value according to the deviation angle with regard to the centre of vision.

$$(2) \quad f(\theta) = \cos\alpha$$

The "weight" function $f(\theta)$ is usually the cosine function [8]. However, knowledge of the physiology of the eye gives rise to the proposal of other alternative functions in this article. The central region of the fovea has the highest density of cones [9]. At 10% eccentricity, the cone density is 100 times lower than in the center, and at 40º eccentricity, the density is 2000 times lower. The cone density justifies the fact that visual acuity is maximal in the center of the field of vision. An eccentricity of 10º implies a visual capacity ten times lower, while 60º eccentricity means that the visual capacity is 100 times lower. Bearing in mind these relations, the authors of the article propose four functions (alternatives to the cosine function) to weigh the prominence of luminances in the field of vision. Two functions are exponential (functions 3 and 4), while two functions stem from the Lorentz function, with two different width constants (function 5).

$$(3) \quad f(\theta) = e^{\frac{-\alpha^2}{c^2}}$$

Where:

α is the deviation angle with regard to the centre of vision;
c = 5º.

(4) $f(\theta) = e^{\frac{-\alpha^4}{c^4}}$

Where:

α is the deviation angle with regard to the centre of vision;
c = 5º.

(5) $f(\theta) = \dfrac{1}{1+\left(\dfrac{\alpha}{c}\right)^2}$

Where:

α is the deviation angle with regard to the centre of vision;
c = 5º in the first case and c = 10º in the second.

Figure 2 compares all five functions. The four functions proposed differ considerably from the cosine function. They all accentuate the value of luminances present in the centre of vision and drastically lower the peripheral luminances. The one that does this the most mildly is the Lorentz function (c=10º).

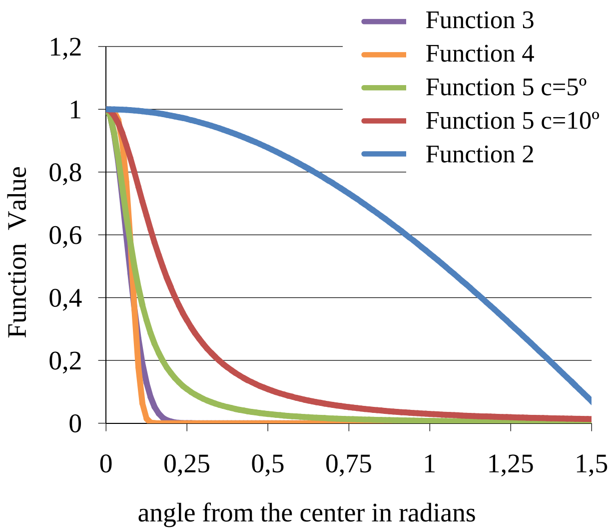

Figure 2: Comparative graph of the 5 weighing functions.

The study then continues by duplicating all the calculations, performing them with both the cosine function and the Lorentz function (c=10º). This system serves to evaluate whether the Lorentz function yields more useful results when evaluating average luminance, and later when evaluating the balance of luminances in the space with regard to an observer.

Finally, we must outline one last clarification. To calculate the average luminance, all of the luminances in the field of vision were considered, including the luminance of the source (window) which is regarded as likely to cause glare.

2.5 Luminance balance of the field of vision

The calculation of the luminance balance present in the field of vision uses the formulation which yields a glare index G and an index DG expressed as: [8] [10]

(6) $G = 10\log_{10} g$

(7) $DG = 2/3(G+14)$

Where:

(8) $g = L_s{}^a \times \omega^b \times f(\theta) / L_b$

With:

L_s being the value of the luminance source;
ω being the value of the light source solid angle;
a and b being coefficients; they are 1.8 and 0.8, respectively;
$f(\theta)$ being the function that weighs the luminance by lowering its value according to the deviation angle with regard to the centre of vision; and
Lb being the luminance value for the background of the light source.

The evaluation of the case studies below considers that the light source (L_s) is a window that provides light from the outdoors, while the background lighting is associated with the average luminance. As mentioned above, the calculation of $f(\theta)$ is duplicated, using both the cosine function and the Lorentz function.

3. CASE STUDY

The case studies test the methodology proposed to evaluate luminance balance. A classroom at the School of Architecture of the Polytechnic University of Catalonia in

Barcelona was the subject of the evaluation. The main feature of the classroom is that its façade is made of a modulation that alternates glass with opaque parts.

Two photographs, in which the only variation is the position of the window with the blinds open (more or less centered) enables us to test the sensitivity of the two formulations being compared (the cosine and Lorentz functions).

First, we took a photograph in which the blackboard is in the center of the vision. In the first version of this photograph (Fig. 3), just one window near the blackboard illuminates the scene. In the second version (Fig. 4), the open blind is far from the blackboard, on the periphery of the field of vision.

Figure 3: Blackboard 1

Figure 4: Blackboard 2

In the second case, the same photographs were taken in the same circumstances with regard to the open blind, but situating a computer screen in the center of vision on the table. The screen remains in both photographs with the same white background (luminance of 89 cd/m^2). Both photographs in which the screen appears in the middle are not included in this article because of its similarities to previous photographs.

4. RESULTS AND DISCUSSION

Table 2 summarizes the results obtained by applying the methodology to the case studies. In all cases, the luminance of the source (the window) is 3700 cd/m^2. Its position is variable, either closer (42º and 54º) or further (72º and 78º) from the centre of the visual field (VF). What is more, the opening of the window leads to slight variations in all the luminances in the scene. The centered window raises the luminances near the blackboard, while the more lateral window boosts the peripheral luminance.

TABLE 2: SUMMARY OF THE RESULTS

VF	L_s	α	$f(\theta)$	L_{med}	G	DG
Blackboard 1	3700	42	Cos	188	33	31
			Lor	96	25	26
Blackboard 2	3700	72	Cos	102	32	31
			Lor	56	22	24
Screen 1	3700	54	Cos	177	32	31
			Lor	92	23	25
Screen 2	3700	78	Cos	90	31	30
			Lor	64	21	23

The results on this table correspond to the results obtained by processing the image using WebHDR and to the geometric screen corresponding to the “equisolid angle” projection. The results of the authors’ own software which evaluates the behavior pixel by pixel yields similar values. Therefore, this exercise enables us to validate the results obtained with both methods of calculation.

The discussion of the results addresses two issues (the value of the L_{med} and of the G index), which enables them to be distinguished even though they bear a close relationship to each other. We should recall that the new weighing via the Lorentz function changes the result of both concepts (L_{med} and the G index).

With regard to L_{med}, the results with the classic formulation (cosine) are more sensitive to the window position. Its values are higher since the luminance of the window has an important relative weight. In contrast, the results with the formulation proposed (Lorentz) are less sensitive to the window position. The resulting average luminance bears a close relationship to the luminances that predominate in the center of the field of vision. Therefore, its values are lower and less changing if the position of the open blind varies. It is acceptable to say that the new L_{med} attempts to be more faithful to the visual faculties of the eye, which sees more centered luminances more easily.

With regard to the G index, the results with the classic (cosine) formula are extremely high and largely exceed the maximum index of the classification (equal to 28), which describes situations with no comfort which are considered intolerable. In contrast, the experience at the time the photographs were taken and the results shown in the pictures enable us to state that the problem is not so dire and that the effect of the glare does not correspond to the results of the cosine formulation. The same evaluation methodology applied with the weight of the Lorentz function offers results which appear to be more in line with reality.

Another factor which deserves mention in relation to the G index is the differing sensitivity of both formulations (cosine and Lorentz) to the position of the light source. With the cosine function, the G index undergoes hardly any variation (one unit) when the open blind varies. However, as expressed in the reflection above, both experience and the photographs convey the sense of varying comfort, as the scenes in which the light source is more centered may be noticeably more uncomfortable. Once again, the same methodology, weighed using the Lorentz function, seems to more faithfully capture this sensation. The G index varies more when the position of the light source varies. In the case of the blackboard, the G index varies three units, while in the case of the screen it varies two units.

With regard to the DG index, the results and the conclusions are similar to those obtained with the G index.

5. CONCLUSION

This article starts with the existing methodologies to evaluate the balance of luminances and the risk of glare. The goal is to modify the function that weighs the importance of luminances in the field of vision (while remaining faithful to the human eye) in order to be able to apply the same methodology to scenes with daylighting (with more extensive and intense light sources than in the case of artificial lighting). The proposed weighing function (Lorentz) offers convincing results for two reasons. First, the glare indexes are lower, bringing them closer to the sensation noticed by users, and secondly, it is more sensitive to changes in the window position, showing that more centered light sources are more uncomfortable for users.

6. ACKNOWLEDGEMENTS

The authors would like to thank Axel Jacobs and his team for their generosity in offering the scientific community unlimited use of their WebHDR software. Without a doubt, this tool facilitates studies that address light comfort in architectural spaces.

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CURRICULUM VITAE

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CV

Standard DRAC form

Number of pages: 7

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Date: 23 /september /2014

Signature: Aguilar, A.

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- ☐ Other

Commitment

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2. Assistant	**2.** Universitat Politècnica de Catalunya	**2.** 01/09/2010 - 31/08/2011

A. Publications

A.2 Conference papers

Authors: López, J.; Coch, H.; Isalgue, A.; Alonso, C.; Aguilar, A.

Research groups : AIEM - Architecture, energy and environment

Title: The Perception of Light Affected by Colour Surfaces in Indoor Spaces

Pages (first-last): 469-474 **Type of document:** Article-Conference Paper

ISBN: 978-2-8399-1280-8 **Legal deposit no.:**

Published: CISBAT 2013 - International Conference. Cleantech For Smart Cities & Buildings. From Nano to Urban Scale.. 2013.

URL to publication:

Conference edition: Clean Technology for Smart Cities & Buildings. From nano to urban scale

Type of conference edition: Conference **Year:** 2013

Town/city: Lausanne **Country:** Switzerland

Authors: Curreli, A.; Coch, H.; Aguilar, A.

Research groups : AIEM - Architecture, energy and environment

Title: Solar potential of roofs : an index for different urban layouts

Pages (first-last): **Type of document:** Article-Conference Paper

ISBN: **Legal deposit no.:**

Published: PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture. 2012.

URL to publication:

Conference edition: PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture

Type of conference edition: Conference **Year:** 2012

Town/city: Lima **Country:** Peru

Authors: Aguilar, A.; Uriarte, U.; Isalgue, A.; Coch, H.; Serra, R.

Research groups : AIEM - Architecture, energy and environment

Title: Luminances and vision related to daylighting

Pages (first-last): 1-6 **Type of document:** Article-Conference Paper

ISBN: 978-1-938547-05-8 **Legal deposit no.:**

Published: Proceedings of the World Renewable Energy Forum. 2012.

URL to publication:

Conference edition: WREC 2012 - World Renewable Energy Congress

Type of conference edition: Conference **Year:** 2012

Town/city: Denver, Colorado **Country:** United States of America

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Authors: Alonso, C.; Aguilar, A.; Coch, H.; Isalgue, A.

Research groups : AIEM - Architecture, energy and environment

Title: Potential for energy saving in transitional spaces in commercial buildings

Pages (first-last): 547-552 **Type of document:** Article-Conference Paper

ISBN: 978-2-8399-0906-8 **Legal deposit no.:**

Published: CLEANTEH FOR SUSTAINABLE BUILDINGS - FROM NANO TO URBAN SCALE. 2011.

URL to publication: http://cisbat.epfl.ch/

Conference edition: CleanTech for Sustainable Buildings - From Nano to Urban Scale

Type of conference edition: Conference **Year:** 2011

Town/city: Lausanne **Country:** Switzerland

Authors: Aguilar, A.; Alonso, C.; Coch, H.; Serra, R.

Research groups : AIEM - Architecture, energy and environment

Title: Solar radiation and architectural design in Barcelona

Pages (first-last): 59 Vol2-64 Vol2 **Type of document:** Article-Conference Paper

ISBN: 978-2-87463-277-8 **Legal deposit no.:** D/2011/9964/19

Published: Architecture & sustainable development. 2011.

URL to publication: http://pul.uclouvain.be/nl/imprimable/?GCOI=29303100045930

Conference edition: 27th International Conference on Passive and Low Energy Architecture

Type of conference edition: Conference **Year:** 2011

Town/city: Louvain-La-Neuve **Country:** Belgium

B. Conferences, courses and other events

B.2 Imparting courses

Authors: Aguilar, A.

Research groups : AIEM - Architecture, energy and environment

Title of paper: Mediciones térmicas en las envolventes de los edificios

Date of presentation: 17/03/2011 **Hours given:** 12

Name of course or seminar: Mediciones térmicas en las envolventes de los edificios

Type of edition: Seminar **Year:** 2011

School:

Town/city: Barcelona **Country:** Espanya

B.7 Provide of conference

Authors: Aguilar, A.

Research groups : AIEM - Architecture, energy and environment

Title of provide conference: Solar radiation and architectural design in Barcelona

Data celebració:07/2011

Name of conference or cycle:PLEA 2011 - 27th Conference on Passive and Low Energy Architecture

Type of conference: Altres

Town/city: Louvain-la-Neuve **Country:** Belgium

Published: Architecture and Sustainable development. 2011. p.59 Vol2-64 Vol2.

Link to presentation: http://www.plea2011.be/

C. Projects and intellectual and industrial property

C.1 Participation in R&D calls

Type of participation: Researcher

Research groups : AIEM - Architecture, energy and environment

Code of funding body : ENE2009-11540

Title: MEDIO AMBIENTE ARQUITECTÓNICO URBANO Y SOSTENIBLE

Start date: 01/01/2010 **End date:** 31/12/2012 **Duration:** 3 Year/s

Funding: 36300.00 € **Scope:** National **Participants:** 1

Institution in which the research was undertaken: Department of Architectural Technology I

Funding bodies: Ministerio de Ciencia e Innovación (MICINN)

Participating institutions:

Head researcher: Coch, H.

G. Stays and other activities

G.1 Stays in R&D centres

Type of participation: Guest

Name of centre: University of Westminster - School of Architecture and Build Environment

Type of centre: University school or faculty **Type of stay:** Doctoral thesis

Town/city: Londres **Country:** United Kingdom

Start date: 01/05/2013 **End date:** 31/12/2013 **Duration:** 8 Month/s

Comparable tasks: Beca AGAUR (BGE-DGR 2012) - Modalitat A: Beques i ajuts per a estades per activitats de recerca a l'estranger.
Títol de la recerca: Advanced methods to evaluate daylighting in architecture.
Investigador responsable: Mike Wilson

H. Actividades de docencia

H.1 Subject taught

Code course: 35929 **Course:** Architectural Environmental Evaluation II

Credits course: 5.0

Hours laboratory/directed activities/theory/practice: - / - / 15.0 / -

Academic year: 2013 **Semester:** Segon Quadrimestre **Course/level:** 1

Body: Universitat Politècnica de Catalunya

School: Postgraduate Office

Cycle: Segon

Type course: Obligatòria **Type program:** Master oficial

Code course: 210011 **Course:** Conditioning and Services I

Credits course: 6.0

Hours laboratory/directed activities/theory/practice: - / - / - / 15.0

Academic year: 2013 **Semester:** Segon Quadrimestre **Course/level:** 1

Body: Universitat Politècnica de Catalunya

School: Barcelona School of Architecture

Cycle: Primer

Type course: Obligatòria **Type program:** Graduat/da

Code course: 210011 **Course:** Conditioning and Services I
Credits course: 6.0
Hours laboratory/directed activities/theory/practice: - / - / - / 31.33
Academic year: 2012 **Semester:** Primer Quadrimestre **Course/level:** 1
Body: Universitat Politècnica de Catalunya
School: Barcelona School of Architecture
Cycle: Primer
Type course: Obligatòria **Type program:** Graduat/da

Code course: 210011 **Course:** Conditioning and Services I
Credits course: 6.0
Hours laboratory/directed activities/theory/practice: - / - / - / 28.0
Academic year: 2012 **Semester:** Segon Quadrimestre **Course/level:** 1
Body: Universitat Politècnica de Catalunya
School: Barcelona School of Architecture
Cycle: Primer
Type course: Obligatòria **Type program:** Graduat/da

Code course: 11261 **Course:** Conditioning and Services II
Credits course: 4.5
Hours laboratory/directed activities/theory/practice: - / - / 30.0 / 15.0
Academic year: 2011 **Semester:** Segon Quadrimestre **Course/level:** 2
Body: Universitat Politècnica de Catalunya
School: Barcelona School of Architecture
Cycle: Segon
Type course: Obligatòria **Type program:** Arquitecte/a

Code course: 210011 **Course:** Conditioning and Services I
Credits course: 6.0
Hours laboratory/directed activities/theory/practice: - / - / - / 28.0
Academic year: 2011 **Semester:** Primer Quadrimestre **Course/level:** 1
Body: Universitat Politècnica de Catalunya
School: Barcelona School of Architecture
Cycle: Primer
Type course: Obligatòria **Type program:** Graduat/da

Code course: 11258 **Course:** Conditioning and Services I
Credits course: 3.0
Hours laboratory/directed activities/theory/practice: - / - / 15.0 / 15.0
Academic year: 2010 **Semester:** Segon Quadrimestre **Course/level:** 2
Body: Universitat Politècnica de Catalunya
School: Barcelona School of Architecture
Cycle: Primer
Type course: Obligatòria **Type program:** Arquitecte/a

Code course: 11261 **Course:** Conditioning and Services II
Credits course: 4.5
Hours laboratory/directed activities/theory/practice: - / - / 30.0 / -
Academic year: 2010 **Semester:** Primer Quadrimestre **Course/level:** 2
Body: Universitat Politècnica de Catalunya
School: Barcelona School of Architecture
Cycle: Segon

Cycle: Segon

Type course: Obligatòria **Type program:** Arquitecte/a

Code course: 11258 **Course:** Conditioning and Services I

Credits course: 3.0

Hours laboratory/directed activities/theory/practice: - / - / 15.0 / 15.0

Academic year: 2009 **Semester:** Segon Quadrimestre **Course/level:** 2

Body: Universitat Politècnica de Catalunya

School: Barcelona School of Architecture

Cycle: Primer

Type course: Obligatòria **Type program:** Arquitecte/a

Code course: 11261 **Course:** Conditioning and Services II

Credits course: 4.5

Hours laboratory/directed activities/theory/practice: - / - / 10.0 / 5.0

Academic year: 2009 **Semester:** Primer Quadrimestre **Course/level:** 2

Body: Universitat Politècnica de Catalunya

School: Barcelona School of Architecture

Cycle: Segon

Type course: Obligatòria **Type program:** Arquitecte/a

Code course: 11261 **Course:** Conditioning and Services II

Credits course: 4.5

Hours laboratory/directed activities/theory/practice: - / - / 10.0 / 5.0

Academic year: 2009 **Semester:** Segon Quadrimestre **Course/level:** 2

Body: Universitat Politècnica de Catalunya

School: Barcelona School of Architecture

Cycle: Segon

Type course: Obligatòria **Type program:** Arquitecte/a

H.2 Coordination teaching

Type coordination: Implantació Noves assignatures (Obligatòries/Categoria-A)

Course academic: 2011

Body: Universitat Politècnica de Catalunya

School: Barcelona School of Architecture

Course: Conditioning and Services I

Hours coordination: 4
